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# RECOMMENDED DESIGN MODIFICATIONS TO THE CH-47 FORWARD ROTOR-DRIVE GEARBOX

Robert H. Badgley

Mechanical Technology, Incorporated

Prepared for:

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13. ABSTRACT


This report describes the results of a study of modifications to existi[ng] helicopter power-train hardware for the purpose of reducing acoustic-frequency vib[ra]tions and noise.

Mechanical vibration analysis methods were put to further tests by applying them to the redesign of CH-47C gearbox components. This program was undertaken carefully and methodically to avoid the excessive costs which often accompany hit-or-miss approaches to gearbox noise reduction. The results include vibration reduction predictions for a number of carefully documented designs.

Since the vibration analysis method for vibration and noise reduction was to be applied to a selected, existing, production aircraft, it was decided to limit the hardware modifications to changes which could possibly be retrofitted without extensive gearbox redesign efforts. Consequently, changes considered do not involve relocation of bearings, changes to bearing sizes, or the like. Instead, shaft noncritical dimensions have been altered, together with the flexibility of the bearing support in one case. In the case of the ring gear, the gear dimensions, number of teeth, and the like are unchanged, while the flexibility of the lower-stage ring-gear support has been altered.

The key products in this overall effort are reduced bearing radial dynamic forces; thus, the results of this program are expected to have major impact upon bearing and gear lifetimes, in addition to the obvious benefits in the area of gearbox noise.


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| Mechanical vibration analysis methods for gearbox noise reduction | | | | | | |



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# USAAMRDL TECHNICAL REPORT 73-33

# RECOMMENDED DESIGN MODIFICATIONS TO THE CH-47 FORWARD ROTOR-DRIVE GEARBOX FOR REDUCTION OF HIGH-FREQUENCY VIBRATION AND NOISE

By

Robert H. Badgley

June 1973

## EUSTIS DIRECTORATE
## U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
## FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-72-C-0040
MECHANICAL TECHNOLOGY INCORPORATED
LATHAM, NEW YORK

DEPARTMENT OF THE ARMY
U. S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by Mechanical Technology Incorporated under the terms of Contract DAAJ02-72-C-0040. It presents a part of a continuing effort to understand and ultimately control the noise produced by helicopter power trains.

This program is an extension of the work presented in USAAVLABS Technical Reports 68-41 and 70-12, and USAAMRDL Technical Report 72-6. This report describes the results of the application of previously developed techniques to reduce noise levels of an existing aircraft transmission.

This report has been reviewed by this Directorate and is considered to be technically sound. The technical monitor for this contract was E. R. Givens, Technology Applications Division.

Project 1G162207AA72
Contract DAAJ02-72-C-0040
USAAMRDL Technical Report 73-33
June 1973

# RECOMMENDED DESIGN MODIFICATIONS TO THE CH-47 FORWARD ROTOR-DRIVE GEARBOX FOR REDUCTION OF HIGH-FREQUENCY VIBRATION AND NOISE

MTI Report 73TR1

By

Robert H. Badgley

Prepared by

Mechanical Technology Incorporated
Latham, New York

Prepared for

EUSTIS DIRECTORATE
U.S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA



ii.

## SUMMARY

The results obtained in this investigation continue to demonstrate the utility of mechanical vibration analysis methods for reducing the high-frequency vibration and noise produced by portions of the helicopter rotor-drive power train, particularly main transmission gear-carrying shafts and structural elements. The mechanical vibration analysis method for gearbox noise reduction has been under development for several years, and has recently progressed to the stage at which experimental verification has become desirable. Recent tests of a CH-47C forward rotor-drive gearbox under the HLH/ATC program have yielded substantial agreement between test and predicted results, to the extent that the vibration analysis method was used in the HLH drive-train design process.

As a result of the successful nature of the foregoing tests, an effort has been undertaken to put the method to further tests through its application to the redesign of CH-47C gearbox components. The results of this program, which has been undertaken rather carefully and methodically to avoid the excessive costs which often accompany hit-or-miss approaches to gearbox noise reduction, will include vibration reduction predictions for a number of carefully documented designs, together with directly comparable measured reductions.

It must once again be stressed that the key products in this overall effort are reduced bearing radial dynamic forces. The results of this program are thus expected to have a major impact upon bearing and gear lifetimes, in addition to the obvious benefits in the area of gearbox noise.

Since the vibration analysis method for vibration and noise reduction was to be applied to a selected existing, production aircraft, it was decided to limit the hardware modifications to changes which could possibly be retrofitted without extensive gearbox redesign efforts. Consequently, changes considered do not involve relocation of bearings, changes to bearing sizes, or the like. Instead, shaft noncritical dimensions have been altered, together with the flexibility of the bearing support in one case. In the case of the ring gear, the gear dimensions, numbers of teeth, and the like are unchanged, while the flexibility of the lower-stage ring-gear support has been altered.

The modifications considered do, in general, involve the addition of weight to gearbox components, because they are essentially mass-oriented in nature. This type of change is not mandated by the analysis method, but is the natural result of the need to achieve lower radial vibration amplitudes at particular bearing locations. The option of relocating the bearings, which is a possibility in the design of a new gearbox, would considerably reduce the need for additional mass. As in earlier studies, the modifications selected for examination are only <u>representative</u> of many. There may be others which will exhibit greater noise reductions with less weight penalty. The optimum configuration can be determined only by systematic study, and must ultimately be evaluated by a competent gearbox designer prior to implementation. While the results achieved by this study are not all-inclusive,

they represent a significant step forward in controlling the elements responsible for the generation of gearbox noise and similar techniques can be applied to any V/STOL aircraft drive system.

## FOREWORD

This report was prepared by Dr. Robert H. Badgley of Mechanical Technology Incorporated under Contract DAAJ02-72-C-0040 (Project 1G162207AA72). The contract was carried out under the technical cognizance of Mr. E. R. Givens, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

Special credit is due to Mrs. F. Gillham of MTI, who carried out the extensive calculations required for the achievement of the contract objectives, and to Mr. Keith Streifert of MTI, who was responsible for the designs of the modified hardware.

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## INTRODUCTION

Helicopter internal noise has been recognized as a major problem which must be overcome if helicopters are to be a safe and comfortable mode of transportation in the future. High internal noise levels have long been considered inherent to the helicopter, primarily because of the high power levels and the weight associated with insulation and blanketing, which reduces the payload in this type of aircraft on a pound-for-pound basis.

Internal noise levels have not always been considered to bear strongly upon helicopter crew and passenger safety. There is growing concern, however, for the legal aspects of hearing damage to both passengers and crew in military helicopters. Perhaps more importantly, there is apparently some evidence that noise components produced by the CH-47 rotor-drive gearbox, shown in Figure 1, are interfering significantly with internal communications within operating CH-47 aircraft. Crew helmets do not and cannot alleviate this problem, since the noise impinges upon the microphones, as do the spoken words of the crew. Noise and vibration fatigue of both passengers and crew is undoubtedly another important element for consideration.

There is, moreover, an increasing awareness of the fact that noise in operating aircraft gearboxes can be quantitatively related to the presence of high radial dynamic force levels in the main rolling-element bearings. The solution to the noise problem, then, contains within it the seeds of the solution to the bearing-life problem as well. It is further becoming clear that the capability of understanding and predicting the flow of vibration energy within the gearbox is precisely the capability required for the diagnosis of gearbox condition and prognosis of remaining gearbox life. Mechanical vibrations are, in effect, a carrier which, when well understood, can be used to transfer information about potential system failures from their points of origin within the gearbox to sensor locations external to the gearbox.

Reduction of noise levels in existing helicopters, wherever possible, and the achievement of quieter future helicopters through design-level efforts have been recognized by the U.S. Army as important objectives. Consequently, the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, has embarked upon a program to understand the sources of internal helicopter noise, to modify existing hardware to reduce the noise levels emitted by these sources, and to transmit the information learned by these investigations to helicopter manufacturers for incorporation into the design process.

Efforts undertaken to date, [1]* through [10], have shown conclusively that the rotor-drive gearbox is the primary source of noise in medium and large size helicopters. Calculations have predicted, and experimental measurements have confirmed, that nonuniformities in the gear meshes within these gearboxes produce small, but significant, vibrations at the mesh frequencies and their integer multiples. These vibrations are amplified by the torsional and lateral vibration characteristics of the gearbox drive train

*Numbers in brackets refer to literature cited at the end of this report.

components, causing the gearbox casing to vibrate. In effect, the gearbox surface (and sometimes its supporting structure as well) acts like a loudspeaker, greatly amplifying the mesh-produced vibrations. It must be stressed that this behavior has actually been measured in a gearbox operating under load [10], and is not simply a theoretical explanation of the problem.

Throughout the entire program, and particularly during the past year under the HLH/ATC program, continuing efforts have been made to appraise helicopter manufacturing organizations of the successful nature of the mechanical vibrations approach to gearbox noise reduction, and of the importance and utility of all of the analytical tools and measurement techniques being developed.

## DESCRIPTION OF PROGRAM

This initial study of modifications to existing helicopter power train hardware for the purpose of reducing acoustic-frequency vibrations and noise was conducted as a single task. The detailed results are summarized below.

In the vibrations analysis of any system, several distinct types of calculations are required for a complete understanding of the behavior of the system. First, the natural frequency (free-vibration) aspects of the problem must be considered, taking into account the actual support masses and stiffnesses. This analysis yields the natural frequencies of the system, together with the vibration mode shapes which may be expected. The analyst learns from these results the frequency ranges upon which he must concentrate during the second portion of the study, which is an investigation of the response of the system to specific forcing functions. From this part of the analysis, information is gained about the vibration amplitudes which may be expected. The third portion of the study is then usually an analysis of the sensitivity of the system to various changes in such parameters as the amplitude or location of the dynamic forces, the bearing stiffnesses, or the dimensions of the shaft.

The natural frequency properties of the CH-47 forward rotor-drive gearbox components were studied [5], and system responses to expected gear tooth dynamic forces were predicted for both the nominal drive train components and for several modifications thereof. This report summarizes the results of further vibration response studies, and presents several hardware modifications which appear to have considerable promise from a vibration and noise-reduction standpoint. These modifications, which are of the type which may be considered by the gearbox designer during the design process, are obviously only a few of many combinations which may prove useful. They are presented to illustrate the utility of the proven analytical methods.

As a result of the studies reported in [3], [4], and [5], dynamic forces acting at the various gear meshes were available, together with rolling-element bearing stiffnesses and gear shaft lateral vibration natural frequencies. Following the procedures outlined in [5], calculations were performed to show the response of the input bevel shaft, including dynamic bearing forces, to the dynamic forces generated at the gear teeth as a result of the gear-tooth mesh characteristics. Such calculations were performed for a number of different shaft configurations and for several different thrust bearing radial stiffness arrangements.

Calculations were conducted for the lower-stage planetary sun gear shaft for a number of shaft modifications. These modifications were limited to changes in shaft dimensions, which could be undertaken with a minimum of disturbance to the existing design (i.e., bearing locations and types, bearing mounting configurations, etc.).

A number of potentially useful modified ring-gear mounting geometries were

conceived and discussed with CH-47 helicopter design engineering personnel. Of the modified configurations, several were identified as promising and were selected for further analysis. In each case, the major objective of the design modification was the isolation of the lower gearbox structure from dynamic gear tooth forces produced at the planet-to-ring gear meshes in the lower stage planetary reduction. This objective was selected after examination of test data obtained in the HLH/ATC gearbox test program.

Designs which meet this objective should result in substantially quieter lower portions of the gearbox at the lower planetary mesh frequency. It should be noted that this may result in higher vibration levels in the cover and mounting arms of the gearbox, but the resulting noise will be produced at the upper surfaces of the gearbox. It will thus be directed away from the helicopter interior, and may more easily be treated by standard acoustic procedures. Complete isolation of the ring gears, through the use of elastomer materials, was rejected for this preliminary study since it represented too radical a change from the existing design. Such isolation, achieved through careful engineering effort by helicopter gearbox design personnel, may yield substantial improvements over and above the results reported herein, and should not arbitrarily be ruled out.

## MODIFICATIONS TO CH-47 FORWARD ROTOR-DRIVE GEARBOX INPUT BEVEL PINION SHAFT AND BEARING SYSTEM

A number of physical modifications of the input bevel pinion shaft and bearing system, shown in Figure 2, have been studied for the purpose of reducing acoustic-frequency vibration. These modifications include changes to noncritical shaft dimensions (e.g., inner diameters) and to the relative amount of radial support to the thrust-carrying ball bearings.

Vibration and noise components at both the spiral bevel mesh and lower-stage planetary mesh frequencies peaked at an input shaft speed of about 7000 rpm during tests reported in [10] (lower-stage planetary mesh frequency of 1480 Hz and bevel mesh frequency of 3390 Hz). Consequently, calculations of input bevel pinion response were made at both of these frequencies. In each case, the dynamic force levels used to force the shaft at the bevel mesh location were calculated by computer program TORRP [3] at the corresponding frequencies. Calculations are for 80 percent of maximum gearbox torque ($1.06 \times 10^6$ lb-in. on the rotor shaft).

The modifications and their resulting vibration amplitudes are shown in Figures 3 through 8. Of the six structural changes to the drive shaft itself, Modification No. 5 yields the best reduction of shaft amplitude at the locations of all bearings at both excitation frequencies.

In Modifications No. 1 - 6, the following stiffnesses were used for the bearings shown in Figure 2:

| Bearing Number | Vertical (X) Stiffness (lb/in.) | Horizontal (Y) Stiffness (lb/in.) | Notes |
|---|---|---|---|
| 1 | $5.0 \times 10^6$ | $6.1 \times 10^6$ | Full value of calculated bearing stiffness |
| 2 | $1.8 \times 10^6$ | $2.2 \times 10^6$ | 15% of calculated bearing stiffness |
| 3 | $1.8 \times 10^6$ | $2.6 \times 10^6$ | 15% of calculated bearing stiffness |
| 4 | $4.8 \times 10^6$ | $8.3 \times 10^6$ | Full value of calculated bearing stiffness |

In Modification No. 7, which has the same mass distribution as Modification No. 5, the stiffnesses of bearings No. 2 and 3 were increased to their full calculated values. In effect, this assumes that the two thrust bearings are mounted such that their outer races are rigidly supported in the radial direction. The results of this modification are shown in Figure 9.

Summaries of the peak dynamic forces in the input bevel gear shaft bearings are presented in Tables I and II for the seven modifications considered.

TABLE I. CALCULATED DYNAMIC FORCES IN CH-47 INPUT BEVEL GEAR SHAFT BEARINGS AT 1480 HZ

| Modification | Peak Forces (lb) Bearing 1 | Bearing 2 | Bearing 3 | Bearing 4 |
|---|---|---|---|---|
| Nominal | 336 | 20 | 131 | 1587 |
| 1 | 214 | 58 | 162 | 1330 |
| 2 | 384 | 21 | 125 | 1577 |
| 3 | 274 | 52 | 167 | 1325 |
| 4 | 563 | 58 | 312 | 3011 |
| 5 | 109 | 13 | 65 | 634 |
| 6 | 55 | 41 | 95 | 622 |
| 7 | 173 | 70 | 243 | 662 |

TABLE II. CALCULATED PEAK DYNAMIC BEARING FORCES IN CH-47 INPUT BEVEL GEAR SHAFT BEARINGS AT 3390 HZ

| Modification | Peak Forces (lb) Bearing 1 | Bearing 2 | Bearing 3 | Bearing 4 |
|---|---|---|---|---|
| Nominal | 350 | 226 | 276 | 719 |
| 1 | 295 | 203 | 254 | 645 |
| 2 | 688 | 389 | 421 | 835 |
| 3 | 788 | 397 | 428 | 661 |
| 4 | 218 | 151 | 186 | 464 |
| 5 | 119 | 93 | 119 | 321 |
| 6 | 158 | 155 | 191 | 360 |
| 7 | 15 | 52 | 127 | 187 |

Table III shows the weight for each modification analyzed. Sample calculations for Modification No. 7 are shown in Table IV.

TABLE III. CALCULATED WEIGHT FOR CH-47 INPUT SPIRAL BEVEL GEAR SHAFT

| Model | Weight (lb) |
|---|---|
| Nominal | 38.1 |
| Modification No. 1 | 42.1 |
| Modification No. 2 | 41.6 |
| Modification No. 3 | 48.2 |
| Modification No. 4 | 47.9 |
| Modification No. 5 | 55.0 |
| Modification No. 6 | 79.9 |
| Modification No. 7 | 55.0 |

## TABLE IV. SAMPLE CALCULATIONS FOR FINAL MODIFICATION FOR CH-47 INPUT BEVEL GEAR SHAFT

CH-47 SPIRAL BEVEL SHAFT - MODIFICATION NO. 7

| INTERCONN. | NO.SPEEDS | INPUT | KPT | N3G | BRCH END | IPOS | NINPUT | NGOUT |
|---|---|---|---|---|---|---|---|---|
| 0 | 2 | 1 | 0 | 4 | -0 | -0 | -0 | -0 |

DATA FOR ROTOR NO.1

| STATIONS | BEARINGS | UNBALANCES | RIG/FLEX.PED | BRCH.PT | BRCH.STAT | ST.MATR | KYM | NDST | NSHM |
|---|---|---|---|---|---|---|---|---|---|
| 28 | 4 | 1 | 0 | 30 | 0 | 0 | 1 | 1 | 1 |

ROTOR DATA

| STATION | MASS.LBS | POLAR MOM.IN. | TRANSV.MOM.IN | LENGTH | OBT.DIA(STIFF) | OUT.DIA(MASS) | INNER DIA. |
|---|---|---|---|---|---|---|---|
| 1 | 3.000000E+00 | 0. | 0. | 4.500000E-01 | 7.100000E+00 | 4.201000E+00 | 4.200000E+00 |
| 2 | 2.246000E+00 | 2.206300E+01 | 1.441600E+01 | 3.500000E-01 | 4.200000E+00 | 2.801000E+00 | 2.800000E+00 |
| 3 | 1.123000E+00 | 0. | 0. | 3.500000E-01 | 2.900000E+00 | 2.101000E+00 | 2.100000E+00 |
| 4 | 0. | 0. | 0. | 7.000000E-01 | 2.000000E+00 | 2.500000E+00 | 0. |
| 5 | 0. | 0. | 0. | 1.000000E+00 | 2.000000E+00 | 2.500000E+00 | 0. |
| 6 | 0. | 0. | 0. | 7.000000E-01 | 2.000000E+00 | 2.500000E+00 | 0. |
| 7 | 0. | 0. | 0. | 2.000000E-01 | 2.000000E+00 | 2.000000E+00 | 0. |
| 8 | 0. | 0. | 0. | 8.000000E-01 | 2.320000E+00 | 3.000000E+00 | 0. |
| 9 | 0. | 0. | 0. | 1.500000E-01 | 2.320000E+00 | 2.320000E+00 | 0. |
| 10 | 0. | 0. | 0. | 3.500000E-01 | 2.320000E+00 | 2.320000E+00 | 0. |
| 11 | 0. | 0. | 0. | 4.000000E-01 | 4.000000E+00 | 4.400000E+00 | 2.200000E+00 |
| 12 | 0. | 0. | 0. | 4.000000E-01 | 4.320000E+00 | 4.320000E+00 | 3.600000E+00 |
| 13 | 0. | 0. | 0. | 7.000000E-01 | 4.320000E+00 | 4.750000E+00 | 3.600000E+00 |
| 14 | 0. | 0. | 0. | 7.000000E-01 | 4.320000E+00 | 4.750000E+00 | 3.600000E+00 |
| 15 | 0. | 0. | 0. | 1.000000E+00 | 4.320000E+00 | 4.650000E+00 | 3.600000E+00 |
| 16 | 0. | 0. | 0. | 6.000000E-01 | 4.320000E+00 | 4.950000E+00 | 3.600000E+00 |
| 17 | 0. | 0. | 0. | 7.000000E-01 | 4.320000E+00 | 4.950000E+00 | 3.600000E+00 |
| 18 | 0. | 0. | 0. | 6.000000E-01 | 4.320000E+00 | 5.020000E+00 | 3.600000E+00 |
| 19 | 0. | 0. | 0. | 6.000000E-01 | 4.320000E+00 | 5.020000E+00 | 3.600000E+00 |
| 20 | 0. | 0. | 0. | 1.000000E+00 | 4.320000E+00 | 4.800000E+00 | 3.600000E+00 |
| 21 | 0. | 0. | 0. | 7.000000E-01 | 5.000000E+00 | 5.600000E+00 | 3.600000E+00 |
| 22 | 0. | 0. | 0. | 7.000000E-01 | 5.000000E+00 | 5.600000E+00 | 3.600000E+00 |
| 23 | 3.637000E-01 | 4.100000E-01 | 2.060000E-01 | 4.500000E-01 | 5.220000E+00 | 5.220000E+00 | 3.600000E+00 |
| 24 | 0. | 0. | 0. | 4.000000E-01 | 6.500000E+00 | 6.500000E+00 | 3.600000E+00 |
| 25 | 0. | 0. | 0. | 7.500000E-01 | 7.000000E+00 | 7.000000E+00 | 0. |
| 26 | 0. | 0. | 0. | 5.000000E-01 | 6.200000E+00 | 6.200000E+00 | 0. |
| 27 | 0. | 0. | 0. | 8.000000E-01 | 5.400000E+00 | 5.400000E+00 | 0. |
| 28 | 0. | 0. | 0. | 0. | 1.000000E+00 | 0. | 0. |

| STATION | YOUNGS MOD. | DENSITY | (SHAPE FACT)*G |
|---|---|---|---|
| 1 | 2.900000E+07 | 2.810000E-01 | 8.250000E+06 |

# TABLE IV (continued)

BEARING STATIONS
14 17 19 22

BEARING DATA

BEARING AT STATION 14

| KXX | W*BXX | KXY | W*BXY | KYδ | W*BYX | KYY | W*BYY |
|---|---|---|---|---|---|---|---|
| 5.000000E+06 | 1.000000E+00 | 0. | 0. | 0. | 0. | 6.120000E+06 | 1.000000E+00 |
| **GXX** | **W*DXX** | **GXY** | **W*DXY** | **GYδ** | **W*DYX** | **GYY** | **W*DYY** |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |

BEARING AT STATION 17

| KXX | W*BXX | KXY | W*BXY | KYδ | W*BYX | KYY | W*BYY |
|---|---|---|---|---|---|---|---|
| 1.200000E+07 | 0. | 0. | 0. | 0. | 0. | 1.470000E+07 | 0. |
| **GXX** | **W*DXX** | **GXY** | **W*DXY** | **GYδ** | **W*DYX** | **GYY** | **W*DYY** |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |

BEARING AT STATION 19

| KXX | W*BXX | KXY | W*BXY | KYδ | W*BYX | KYY | W*BYY |
|---|---|---|---|---|---|---|---|
| 1.180000E+07 | 0. | 0. | 0. | 0. | 0. | 1.720000E+07 | 0. |
| **GXX** | **W*DXX** | **GXY** | **W*DXY** | **GYδ** | **W*DYX** | **GYY** | **W*DYY** |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |

BEARING AT STATION 22

| KXX | W*BXX | KXY | W*BXY | KYδ | W*BYX | KYY | W*BYY |
|---|---|---|---|---|---|---|---|
| 4.800000E+06 | 0. | 0. | 0. | 0. | 0. | 8.320000E+06 | 0. |
| **GXX** | **W*DXX** | **GXY** | **W*DXY** | **GYδ** | **W*DYX** | **GYY** | **W*DYY** |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |

CUMULATIVE DATA FOR ROTOR NO. 1

| STATION | CUM.LENGTH | ELEMENT WEIGHT | CUM.WEIGHT |
|---|---|---|---|
| 1 | 0.00000 | 3.0008 | 3.0000 |
| 2 | .45000 | 2.2464 | 5.2468 |
| 3 | .80000 | 1.1233 | 6.3703 |
| 4 | 1.15000 | .9655 | 6.3706 |
| 5 | 1.85000 | 1.3794 | 7.3361 |
| 6 | 2.85000 | .9655 | 8.7155 |
| 7 | 3.55000 | .1766 | 9.6810 |
| 8 | 3.75000 | 1.5890 | 9.8576 |
| 9 | 4.55000 | .1782 | 11.4466 |
| 10 | 4.70000 | .4158 | 11.6248 |
| 11 | 5.05000 | 1.2818 | 12.0406 |
| 12 | 5.45000 | .5034 | 13.3224 |
| 13 | 5.85000 | 1.4835 | 13.8258 |
| 14 | 6.55000 | 1.4835 | 15.3092 |
| 15 | 7.25000 | 1.9118 | 16.7927 |
| 16 | 8.25000 | 1.5284 | 18.7045 |
| 17 | 8.85000 | 1.7832 | 20.2329 |
| 18 | 9.55000 | 1.6209 | 22.0161 |
| 19 | 10.15000 | 1.6209 | 23.6370 |
| 20 | 10.75000 | 2.2246 | 25.2576 |
| 21 | 11.75000 | 2.8426 | 27.4824 |
| 22 | 12.45000 | 2.8426 | 30.3250 |
| 23 | 13.15000 | 1.7627 | 33.5313 |
| 24 | 13.60000 | 2.5857 | 34.9503 |
| 25 | 14.00000 | 8.1106 | 37.5360 |
| 26 | 14.75000 | 4.2418 | 45.6466 |
| 27 | 15.25000 | 5.1484 | 49.8884 |
| 28 | 16.05000 | 0.0080 | 55.0368 |

TOTAL SYSTEM WEIGHT= 55.0368

| FIRST SPEED | LAST SPEED | SPEED INCR. | FREQUENCY | FREQ/SPEED | DAMPING FACTOR |
|---|---|---|---|---|---|
| 7.000000E-03 | [illegible].000000E-02 | 1.000000E-02 | 3.390000E-03 | -0. | 1.000000E+00 |

FORCE EXCITATION DATA FOR ROTOR 1

| STATION | F-X.COS.COMP | F-X.SIN.COMP | F-Y.COS.COMP | F-Y.SIN.COMP |
|---|---|---|---|---|
| 26 | 1.265400E+02 | 0. | -6.751240E+02 | 0. |

## TABLE IV (continued)

ROTOR SPEED= 7.000000E+03 RPM

EXCITATION FREQUENCY= 3.390000E+03 CPS

AMPLITUDES FOR ROTOR NO. 1

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE | X-AMPLITUDE | X-PHASE ANGLE | Y-AMPLITUDE | Y-PHASE ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 3.212802E-07 | -1.911466E-07 | 1.066015E+02 | 1.143640E+02 | 2.048916E-07 | 2.511452E+02 | 3.126938E-07 | 8.770393E+01 |
| 2 | 2.229629E-06 | -1.408029E-07 | 9.485551E+01 | 9.495159E+01 | 2.351591E-07 | 2.167234E+02 | 2.221660E-06 | 8.978872E+01 |
| 3 | 3.705258E-06 | -9.902157E-08 | 9.437896E+01 | 9.442158E+01 | 2.996409E-07 | 1.992812E+02 | 3.694449E-06 | 8.992537E+01 |
| 4 | 5.112275E-06 | -5.620350E-08 | 9.418435E+01 | 9.421449E+01 | 3.772093E-07 | 1.885762E+02 | 5.098650E-06 | 8.998426E+01 |
| 5 | 6.742304E-06 | 6.752967E-08 | 9.401531E+01 | 9.403737E+01 | 4.768982E-07 | 1.719016E+02 | 6.725756E-06 | 9.006234E+01 |
| 6 | 6.790266E-06 | 2.301586E-07 | 9.412110E+01 | 9.413058E+01 | 5.392814E-07 | 1.548155E+02 | 6.772729E-06 | 9.014941E+01 |
| 7 | 5.734706E-06 | 3.069693E-07 | 9.452259E+01 | 9.449932E+01 | 5.460069E-07 | 1.458893E+02 | 5.716901E-06 | 9.021932E+01 |
| 8 | 5.354224E-06 | 3.208364E-07 | 9.473004E+01 | 9.468767E+01 | 5.451345E-07 | 1.440457E+02 | 5.336054E-06 | 9.024171E+01 |
| 9 | 4.105569E-06 | 3.414265E-07 | 9.608992E+01 | 9.590188E+01 | 5.522404E-07 | 1.418769E+02 | 4.082561E-06 | 9.032031E+01 |
| 10 | 3.896633E-06 | 3.401229E-07 | 9.646271E+01 | 9.622996E+01 | 5.537151E-07 | 1.421522E+02 | 3.872259E-06 | 9.033371E+01 |
| 11 | 3.495117E-06 | 3.313875E-07 | 9.748228E+01 | 9.712568E+01 | 5.613388E-07 | 1.438174E+02 | 3.465626E-06 | 9.035685E+01 |
| 12 | 3.416373E-06 | 3.169099E-07 | 9.852566E+01 | 9.807362E+01 | 5.956102E-07 | 1.477992E+02 | 3.378947E-06 | 9.034466E+01 |
| 13 | 3.368979E-06 | 2.946416E-07 | 1.000055E+02 | 9.938581E+01 | 6.070497E-07 | 1.508264E+02 | 3.022737E-06 | 9.035068E+01 |
| 14 | 2.564771E-06 | 2.468362E-07 | 1.031540E+02 | 1.022057E+02 | 6.312153E-07 | 1.566692E+02 | 2.498108E-06 | 9.034024E+01 |
| 15 | 2.545964E-06 | 2.131764E-07 | 1.058296E+02 | 1.047596E+02 | 7.243936E-07 | 1.624834E+02 | 2.451066E-06 | 9.028946E+01 |
| 16 | 2.986275E-06 | 1.556875E-07 | 1.069463E+02 | 1.062035E+02 | 8.830727E-07 | 1.695480E+02 | 2.856967E-06 | 9.016728E+01 |
| 17 | 3.566559E-06 | 1.177148E-07 | 1.060735E+02 | 1.056251E+02 | 9.939335E-07 | 1.730170E+02 | 3.427287E-06 | 9.009646E+01 |
| 18 | 5.546242E-06 | 9.783596E-08 | 1.041403E+02 | 1.039323E+02 | 1.358257E-06 | 1.757867E+02 | 5.378245E-06 | 9.004655E+01 |
| 19 | 7.486891E-06 | 7.902496E-08 | 1.028360E+02 | 1.027235E+02 | 1.655080E-06 | 1.772352E+02 | 7.299814E-06 | 9.002525E+01 |
| 20 | 1.164201E-05 | 7.450495E-08 | 1.012349E+02 | 1.011773E+02 | 2.269402E-06 | 1.780971E+02 | 1.141892E-05 | 9.001524E+01 |
| 21 | 1.854575E-05 | 6.472245E-08 | 9.984190E+01 | 9.981621E+01 | 3.170669E-06 | 1.788219E+02 | 1.827282E-05 | 9.000900E+01 |
| 22 | 2.265222E-05 | 5.236209E-08 | 9.917939E+01 | 9.916435E+01 | 3.613989E-06 | 1.791654E+02 | 2.230213E-05 | 9.000636E+01 |
| 23 | 2.787269E-05 | 4.083004E-08 | 9.846692E+01 | 9.845910E+01 | 4.104130E-06 | 1.794284E+02 | 2.756891E-05 | 9.000467E+01 |
| 24 | 3.078133E-05 | 3.249567E-08 | 9.813157E+01 | 9.812677E+01 | 4.354037E-06 | 1.795719E+02 | 3.047185E-05 | 9.000384E+01 |
| 25 | 3.315146E-05 | 2.441824E-08 | 9.791398E+01 | 9.791124E+01 | 4.564566E-06 | 1.796937E+02 | 3.283573E-05 | 9.000312E+01 |
| 26 | 3.717080E-05 | 8.691317E-09 | 9.759887E+01 | 9.759902E+01 | 4.915357E-06 | 1.798997E+02 | 3.684437E-05 | 9.000193E+01 |
| 27 | 4.100505E-05 | -1.559412E-09 | 9.744874E+01 | 9.745033E+01 | 5.315864E-06 | 1.800225E+02 | 4.065902E-05 | 9.000122E+01 |
| 28 | 4.657304E-05 | -1.899751E-08 | 9.725686E+01 | 9.726016E+01 | 5.883032E-06 | 1.801868E+02 | 4.619998E-05 | 9.000032E+01 |

| STATION | X MOM-AMPL | X MOM-ANGLE | Y MOM-AMPL | Y MOM-ANGLE | X SHR-AMPL | X SHR-ANGLE | Y SHR-AMPL | Y SHR-ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 9.000000E+01 | 7.223367E-01 | -1.611462E+02 | 1.102386E+00 | 1.822961E+02 |
| 2 | 4.724949E+00 | 7.184394E+01 | 7.127397E+01 | 4.775112E-02 | 1.283432E+00 | -1.452776E+02 | 6.966648E+00 | 1.805411E+02 |
| 3 | 4.375160E+00 | 7.539647E+01 | 6.883542E+01 | 3.027340E-02 | 1.620243E+00 | -1.370282E+02 | 1.184181E+01 | 1.803490E+02 |
| 4 | 3.908310E+00 | 7.985858E+01 | 6.468988E+01 | 9.846301E-03 | 1.620350E+00 | -1.370257E+02 | 1.184549E+01 | 1.803490E+02 |
| 5 | 2.913685E+00 | 9.291007E+01 | 5.410899E+01 | -4.106518E-02 | 1.981727E+00 | -1.265396E+02 | 1.869314E+01 | 1.802108E+02 |
| 6 | 1.535052E+00 | 1.430579E+02 | 2.979273E+01 | -1.895415E-01 | 2.562631E+00 | -1.115737E+02 | 2.994773E+01 | 1.800918E+02 |
| 7 | 2.010011E+00 | -1.521985E+02 | 6.260338E+00 | -1.139290E+00 | 2.987511E+00 | -1.020979E+02 | 3.706941E+01 | 1.800390E+02 |
| 8 | 2.437570E+00 | -1.410503E+02 | 1.281301E+00 | 1.857813E+02 | 3.065599E+00 | -1.005463E+02 | 3.823627E+01 | 1.800309E+02 |
| 9 | 4.756444E+00 | -1.161801E+02 | 3.553424E+01 | 1.802072E+02 | 3.828022E+00 | -8.905348E+01 | 4.701663E+01 | 1.799730E+02 |
| 10 | 5.278150E+00 | -1.132519E+02 | 4.264997E+01 | 1.801677E+02 | 3.921032E+00 | -8.803389E+01 | 4.785114E+01 | 1.799678E+02 |
| 11 | 6.572881E+00 | -1.077856E+02 | 5.971633E+01 | 1.801089E+02 | 4.146416E+00 | -8.586770E+01 | [illegible].963823E+01 | 1.799565E+02 |
| 12 | 8.251050E+00 | -1.025273E+02 | 8.060678E+01 | 1.800654E+02 | 4.920031E+00 | -8.078508E+01 | 5.479255E+01 | 1.799275E+02 |
| 13 | 1.016011E+01 | -9.613548E+01 | 1.020091E+02 | 1.800345E+02 | 5.252514E+00 | -7.936413E+01 | 5.668425E+01 | 1.790183E+02 |
| 14 | 1.401704E+01 | -9.240181E+01 | 1.443185E+02 | 1.799980E+02 | 3.236824E+00 | -8.651164E+01 | 4.618720E+01 | 1.799763E+02 |
| 15 | 1.664492E+01 | -9.104333E+01 | 1.781527E+02 | 1.799913E+02 | 4.379148E+00 | -8.204370E+01 | 5.046823E+01 | 1.799513E+02 |
| 16 | 2.182553E+01 | -8.861531E+01 | 2.314671E+02 | 1.799796E+02 | 6.170551E+00 | -8.036154E+01 | 5.631136E+01 | 1.799326E+02 |
| 17 | 2.598707E+01 | -8.729443E+01 | 2.668843E+02 | 1.799729E+02 | 4.093611E+00 | 9.229723E+01 | 1.153535E+01 | 1.800291E+02 |
| 18 | 2.393820E+01 | -8.713755E+01 | 2.779284E+02 | 1.799740E+02 | 1.638913E+00 | 8.764145E+01 | 2.070104E+01 | 1.799868E+02 |
| 19 | 2.379422E+01 | -8.689396E+01 | 2.937785E+02 | 1.799744E+02 | 1.840010E+01 | 9.220703E+01 | 9.281397E+01 | -2.676768E-02 |
| 20 | 1.382452E+01 | -8.622951E+01 | 2.430416E+02 | 1.799748E+02 | 1.464757E+01 | 9.219181E+01 | 7.500035E+01 | -2.858318E-02 |
| 21 | 2.571485E+00 | -8.007456E+01 | 1.859763E+02 | 1.799774E+02 | 7.502037E+00 | 9.287248E+01 | 3.613875E+01 | -4.712651E-02 |
| 22 | 1.203678E+00 | -7.793724E+01 | 1.836826E+02 | 1.799826E+02 | 1.348648E+01 | 9.183305E+01 | 1.541898E+02 | -1.539781E-02 |
| 23 | 3.979800E+00 | 8.838641E+01 | 1.025220E+02 | 1.799777E+02 | 1.224585E+00 | -1.021251E+02 | 5.883954E+01 | -3.171362E-02 |
| 24 | 1.867306E+00 | 8.967360E+01 | 8.676198E+01 | 1.799828E+02 | 8.256530E+00 | -9.135966E+01 | 1.[illegible]40725E+01 | -1.595676E-01 |
| 25 | 4.124745E+00 | -9.068892E+01 | 1.016061E+02 | 1.799912E+02 | 2.181134E+01 | -9.028728E+01 | 8.56[illegible]E+01 | 1.8001[illegible]E+02 |
| 26 | 3.724623E+01 | -9.009706E+01 | 2.883374E+02 | 1.799992E+02 | 5.946908E+01 | 8.995352E+01 | 4.566[illegible]E+02 | -1.091223E-03 |
| 27 | 1.380851E+01 | -9.013566E+01 | 1.075601E+02 | 1.799994E+02 | 3.394899E+01 | 8.989116E+01 | 2.633091E+02 | -7.446646E-04 |
| 28 | 3.677661E-11 | 1.358219E+02 | 2.246261E-11 | 1.861085E+02 | 4.330238E-11 | 1.260218E+02 | 5.587164E-12 | 1.992909E+01 |

## TABLE IV (continued)

| STATION | MAX.MOMENT | MIN.MOMENT | ANG.X-MAJ.AX | PHASE ANGLE | MAX.STRESS | MIN.STRESS |
|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 0. | 0. | 0. |
| 2 | 7.141522E+01 | -1.473146E+00 | -4.860497E+01 | 1.763683E+02 | 1.223527E+01 | -2.523879E-01 |
| 3 | 6.896550E+01 | -1.103257E+00 | -4.852004E+01 | 1.764539E+02 | 3.972656E+01 | -6.355148E-01 |
| 4 | 6.480419E+01 | -6.876149E-01 | -4.840377E+01 | 1.765699E+02 | 8.251106E+01 | -8.754964E-01 |
| 5 | 5.418718E+01 | 1.497923E-01 | -4.807826E+01 | 1.768892E+02 | 6.899310E+01 | 1.907210E-01 |
| 6 | 2.980691E+01 | 1.229340E+00 | -4.676889E+01 | 1.781146E+02 | 3.795124E+01 | 1.565240E+00 |
| 7 | 6.341667E+00 | 1.736443E+00 | -3.544567E+01 | -1.742237E+02 | 8.074442E+00 | 2.210902E+00 |
| 8 | 2.556743E+00 | -1.023009E+00 | 6.422322E+01 | -1.139245E+02 | 2.085557E+00 | -8.344772E-01 |
| 9 | 3.578967E+01 | -2.098848E+00 | -5.186134E+01 | -7.058434E+00 | 2.919395E+01 | -1.712049E+00 |
| 10 | 4.292475E+01 | -2.084432E+00 | -5.149413E+01 | -6.643147E+00 | 3.501409E+01 | -1.700290E+00 |
| 11 | 6.004339E+01 | -2.008620E+00 | -5.098629E+01 | -6.078370E+00 | 1.051871E+01 | -3.518804E-01 |
| 12 | 8.100821E+01 | -1.789973E+00 | -5.070768E+01 | -5.768788E+00 | 1.976785E+01 | -4.367941E-01 |
| 13 | 1.033995E+02 | -1.437013E+00 | -5.058270E+01 | -5.626016E+00 | 2.523182E+01 | -3.506640E-01 |
| 14 | 1.449964E+02 | -5.841743E-01 | -5.054275E+01 | -5.567189E+00 | 3.538242E+01 | -1.425518E-01 |
| 15 | 1.789284E+02 | -2.992443E-01 | -5.033683E+01 | -5.354501E+00 | 4.[illegible]66260E+01 | -7.302243E-02 |
| 16 | 2.324932E+02 | 5.328267E-01 | -5.038503E+01 | -5.393069E+00 | [illegible]3363E+01 | 1.300218E-01 |
| 17 | 2.681436E+02 | 1.233147E+00 | -5.055531E+01 | -5.556791E+0[illegible] | [illegible]15E+01 | 3.009160E-01 |
| 18 | 2.789548E+02 | 1.201841E+00 | -4.991665E+01 | -4.921406E[illegible] | [illegible]2E+01 | 2.932765E-01 |
| 19 | 2.947377E+02 | 1.295648E+00 | -4.962370E+01 | -4.628916E[illegible] | [illegible]0E+01 | 3.161677E-01 |
| 20 | 2.434327E+02 | 9.137033E-01 | -4.824847E+01 | -3.261487[illegible] | [illegible]2E+01 | 2.279644E-01 |
| 21 | 1.859935E+02 | 4.441972E-01 | -4.578027E+01 | -8.010378[illegible] | [illegible]4E+01 | 4.949852E-02 |
| 22 | 1.836864E+02 | 2.519010E-01 | -4.536714E+01 | -3.840626[illegible] | [illegible]2E+01 | 2.807025E-02 |
| 23 | 1.025992E+02 | 1.104339E-01 | -4.277781E+01 | 2.197483[illegible] | [illegible]97E+00 | 1.022048E-02 |
| 24 | 8.678207E+01 | 1.007355E-02 | -4.376708E+01 | 1.215546[illegible] | [illegible]5.[illegible]083E+00 | 4.124371E-04 |
| 25 | 1.016897E+02 | -4.891688E-02 | -4.732451E+01 | -2.334476[illegible] | [illegible]19828E+00 | -1.452659E-03 |
| 26 | 2.907331E+02 | -6.205565E-02 | -5.236046E+01 | -7.362851E+00 | [illegible].242563E+01 | -2.652203E-03 |
| 27 | 1.084429E+02 | -3.228466E-02 | -5.231557E+01 | -7.318352E+00 | 7.014857E+00 | -2.088402F-03 |
| 28 | 4.113965E-11 | -1.283030E-11 | 1.685515E+01 | 9.920521E+01 | 4.190440E-10 | -1.306881E-10 |

FORCE TO FOUNDATION AT BEARINGS - RIGID PEDESTALS.

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE |
|---|---|---|---|---|
| 14 | 1.556197E+01 | 1.244914E+00 | -7.922382E+01 | -7.975592E+01 |
| 17 | 5.175391E+01 | 1.430988E+00 | -7.676870E+01 | -7.704472E+01 |
| 19 | 1.270813E+02 | 9.449190E-01 | -8.111599E+01 | -8.115733E+01 |
| 22 | 1.868597E+02 | 2.534992E-01 | -8.467383E+01 | -8.467472E+01 |

ROTOR NO. 1 ENERGY IN= 2.085785E-11 ENERGY OUT= 2.085697E-11

ROTOR NO. 2 ENERGY IN= 0. ENERGY OUT= 0.

BOTH ROTORS ENERGY IN= 2.085785E-11 ENERGY OUT= 2.085697E-11

| FIRST SPEED | LAST SPEED | SPEED INCR. | FREQUENCY | FREQ/SPEED | DAMPING FACTOR |
|---|---|---|---|---|---|
| 7.000000E+03 | 1.000000E+02 | 1.000000E+02 | 1.480000E+03 | -0. | 1.000000E+00 |

FORCE EXCITATION DATA FOR ROTOR 1

| STATION | F-X.COS.COMP | F-X.SIN.COMP | F-Y.COS.COMP | F-Y.SIN.COMP |
|---|---|---|---|---|
| 26 | 3.838000E+01 | 0. | -2.654280E+02 | 0. |

## TABLE IV (continued)

ROTOR SPEED= 7.000000E+03 RPM

EXCITATION FREQUENCY= 1.480000E+03 CPS

AMPLITUDES FOR ROTOR NO. 1

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE | X-AMPLITUDE | X-PHASE ANGLE | Y-AMPLITUDE | Y-PHASE ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 6.617476E-05 | 2.246831E-06 | 9.523439E+01 | 9.527131E+01 | 6.438426E-06 | 1.597014E+02 | 6.589912E-05 | 9.021514E+01 |
| 2 | 4.863206E-05 | 2.561390E-06 | 9.524779E+01 | 9.526230E+01 | 5.127532E-06 | 1.502035E+02 | 4.842960E-05 | 9.031167E+01 |
| 3 | 3.561610E-05 | 2.803225E-06 | 9.526768E+01 | 9.529774E+01 | 4.257549E-06 | 1.390625E+02 | 3.486917E-05 | 9.045294E+01 |
| 4 | 2.157777E-05 | 3.029379E-06 | 9.531347E+01 | 9.532955E+01 | 3.610163E-06 | 1.235387E+02 | 2.148689E-05 | 9.076416E+01 |
| 5 | 4.797538E-06 | -3.205324E-06 | 9.435036E+01 | 2.738633E+02 | 3.216741E-06 | 8.301699E+01 | 4.789891E-06 | 2.666033E+02 |
| 6 | 3.267336E-05 | -3.000033E-06 | 9.512110E+01 | 2.751609E+02 | 4.175430E-06 | 4.573459E+01 | 3.254404E-05 | 2.695684E+02 |
| 7 | 4.356316E-05 | -2.635043E-06 | 9.513309E+01 | 2.751751E+02 | 4.698825E-06 | 3.399685E+01 | 4.338910E-05 | 2.697307E+02 |
| 8 | 4.518251E-05 | -2.511062E-06 | 9.513237E+01 | 2.751748E+02 | 4.753093E-06 | 3.179027E+01 | 4.500192E-05 | 2.697564E+02 |
| 9 | 4.642395E-05 | -2.036874E-06 | 9.511797E+01 | 2.751616E+02 | 4.615556E-06 | 2.614293E+01 | 4.623922E-05 | 2.698185E+02 |
| 10 | 4.588399E-05 | -1.948568E-06 | 9.511336E+01 | 2.751573E+02 | 4.526658E-06 | 2.543228E+01 | 4.570172E-05 | 2.698262E+02 |
| 11 | 4.364923E-05 | -1.750346E-06 | 9.509909E+01 | 2.751437E+02 | 4.253219E-06 | 2.424354E+01 | 4.347677E-05 | 2.698396E+02 |
| 12 | 3.991665E-05 | -1.573583E-06 | 9.507545E+01 | 2.751210E+02 | 3.863557E-06 | 2.398006E+01 | 3.976038E-05 | 2.698450E+02 |
| 13 | 3.601890E-05 | -1.360505E-06 | 9.504728E+01 | 2.750942E+02 | 3.466495E-06 | 2.320188E+01 | 3.587944E-05 | 2.698558E+02 |
| 14 | 2.832704E-05 | -1.001498E-06 | 9.497241E+01 | 2.750228E+02 | 2.650251E-06 | 2.216533E+01 | 2.822057E-05 | 2.698741E+02 |
| 15 | 2.275204E-05 | -7.635093E-07 | 9.471217E+01 | 2.747595E+02 | 2.018040E-06 | 2.219927E+01 | 2.267522E-05 | 2.698889E+02 |
| 16 | 1.244697E-05 | -4.823277E-07 | 9.381339E+01 | 2.7[illegible]461E+02 | 9.575402E-07 | 3.020489E+01 | 1.241946E-05 | 2.698847E+02 |
| 17 | 4.741900E-06 | -3.524342E-07 | 9.088537E+01 | 2.797336E+02 | 3.599290E-07 | 7.810229E+01 | 4.741337E-06 | 2.697824E+02 |
| 18 | 4.631150E-06 | 3.197899E-07 | 1.015170E+02 | 1.009575E+02 | 9.762983E-07 | 1.607196E+02 | 4.538354E-06 | 9.024660E+01 |
| 19 | 1.419232E-05 | 3.327409E-07 | 9.768160E+01 | 9.760214E+01 | 1.925503E-06 | 1.700597E+02 | 1.406503E-05 | 9.010173E+01 |
| 20 | 2.927891E-05 | 4.396981E-07 | 9.656960E+01 | 9.655167E+01 | 3.378161E-06 | 1.725527E+02 | 2.908669E-05 | 9.008116E+01 |
| 21 | 5.781874E-05 | 6.792730E-07 | 9.595468E+01 | 9.596021E+01 | 6.036147E-06 | 1.735791E+02 | 5.750680E-05 | 9.007574E+01 |
| 22 | 7.977283E-05 | 8.364388E-07 | 9.568267E+01 | 9.569619E+01 | 7.942744E-06 | 1.739984E+02 | 7.938083E-05 | 9.007336E+01 |
| 23 | 1.080875E-04 | 1.036379E-06 | 9.538860E+01 | 9.540904E+01 | 1.020283E-05 | 1.742163E+02 | 1.076099E-04 | 9.007226E+01 |
| 24 | 1.258336E-04 | 1.159824E-06 | 9.527072E+01 | 9.529379E+01 | 1.161684E-05 | 1.743174E+02 | 1.253016E-04 | 9.007179E+01 |
| 25 | 1.404711E-04 | 1.255117E-06 | 9.520317E+01 | 9.522776E+01 | 1.280019E-05 | 1.744207E+02 | 1.398924E-04 | 9.007121E+01 |
| 26 | 1.668570E-04 | 1.421261E-06 | 9.511552E+01 | 9.514205E+01 | 1.494484E-05 | 1.745912E+02 | 1.661925E-04 | 9.007023E+01 |
| 27 | 1.846779E-04 | 1.530356E-06 | 9.507805E+01 | 9.510543E+01 | 1.641726E-05 | 1.746998E+02 | 1.839531E-04 | 9.006957E+01 |
| 28 | 2.127048E-04 | 1.700860E-06 | 9.503102E+01 | 9.505943E+01 | 1.872993E-05 | 1.748383E+02 | 2.118854E-04 | 9.006874E+01 |

| STATION | X MOM-AMPL | X MOM-ANGLE | Y MOM-AMPL | Y MOM-ANGLE | X SHR-AMPL | X SHR-ANGLE | Y SHR-AMPL | Y SHR-ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 9.000000E+01 | 4.326326E+00 | -6.970141E+01 | 4.428117E+01 | 1.797849E+02 |
| 2 | 2.131502E+01 | -1.415955E+02 | 1.455588E+02 | 1.805572E+02 | 6.884719E+00 | -6.615619E+01 | 6.865529E+01 | 1.797506E+02 |
| 3 | 2.204455E+01 | -1.355222E+02 | 1.695868E+02 | 1.804429E+02 | 7.915043E+00 | -6.387631E+01 | 7.743008E+01 | 1.797275E+02 |
| 4 | 2.306723E+01 | -1.289769E+02 | 1.966859E+02 | 1.803443E+02 | 7.915306E+00 | -6.387554E+01 | 7.743213E+01 | 1.797275E+02 |
| 5 | 2.586229E+01 | -1.172336E+02 | 2.518196E+02 | 1.802053E+02 | 8.379462E+00 | -6.021782E+01 | 7.915257E+01 | 1.796865E+02 |
| 6 | 3.090911E+01 | -1.034402E+02 | 3.286357E+02 | 1.800749E+02 | 8.457875E+00 | -5.269440E+01 | 7.305251E+01 | 1.795977E+02 |
| 7 | 3.468945E+01 | -9.558462E+01 | 3.769848E+02 | 1.800081E+02 | 8.289816E+00 | -4.618930E+01 | 6.470124E+01 | 1.795027E+02 |
| 8 | 3.577444E+01 | -9.355432E+01 | 3.897506E+02 | 1.799912E+02 | 8.248694E+00 | -4.492500E+01 | 6.295137E+01 | 1.794818E+02 |
| 9 | 3.987606E+01 | -8.598974E+01 | 4.335643E+02 | 1.799286E+02 | 7.945227E+00 | -3.320395E+01 | 4.651480E+01 | 1.792247E+02 |
| 10 | 4.059621E+01 | -8.464042E+01 | 4.404031E+02 | 1.799173E+02 | 7.923720E+00 | -3.189507E+01 | 4.467956E+01 | 1.791855E+02 |
| 11 | 4.227218E+01 | -8.159150E+01 | 4.553051E+02 | 1.799918E+02 | 7.883566E+00 | -2.894035E+01 | 4.051729E+01 | 1.790847E+02 |
| 12 | 4.406414E+01 | -7.816993E+01 | 4.690838E+02 | 1.798625E+02 | 7.871409E+00 | -2.045411E+01 | 2.856442E+01 | 1.786357E+02 |
| 13 | 4.575783E+01 | -7.477372E+01 | 4.796389E+02 | 1.798328E+02 | 7.904706E+00 | -1.746832E+01 | 2.429861E+01 | 1.783698E+02 |
| 14 | 4.870036E+01 | -6.901668E+01 | 4.927559E+02 | 1.797799E+02 | 1.401791E+01 | -7.792742E+01 | 1.863178E+02 | 1.798963E+02 |
| 15 | 5.820153E+01 | -7.032191E+01 | 6.200995E+02 | 1.798027E+02 | 1.338083E+01 | -7.605865E+01 | 1.778283E+02 | 1.798857E+02 |
| 16 | 7.126051E+01 | -7.120053E+01 | 7.937522E+02 | 1.798[illegible]E+02 | 1.288145E+01 | -7.429174E+01 | 1.702086E+02 | 1.798758E+02 |
| 17 | 7.893649E+01 | -7.145823E+01 | 8.948542E+02 | 1.798257E+02 | 1.314711E+01 | -9.260263E+01 | 2.369328E+02 | 1.799730E+02 |
| 18 | 8.762906E+01 | -7.360710E+01 | 1.060455E+03 | 1.798486E+02 | 1.330591E+01 | -9.199747E+01 | 2.368301E+02 | 1.799712E+02 |
| 19 | 9.537743E+01 | -7.512291E+01 | 1.203379E+03 | 1.798631E+02 | 9.577539E+00 | 1.164638E+02 | 1.783377E+00 | -9.767687E+00 |
| 20 | 9.001563E+01 | -7.587534E+01 | 1.204387E+03 | 1.798717E+02 | 8.671242E+00 | 1.184369E+02 | 6.035253E+00 | 1.827604E+02 |
| 21 | 8.269318E+01 | -7.745259E+01 | 1.219935E+03 | 1.798863E+02 | 6.559242E+00 | 1.259934E+02 | 2.743174E+01 | 1.805469E+02 |
| 22 | 7.998293E+01 | -7.887821E+01 | 1.253566E+03 | 1.798969E+02 | 3.949233E+01 | 1.007440E+02 | 5.894693E+02 | -1.020896E-01 |
| 23 | 5.418869E+01 | -7.860194E+01 | 8.591667E+02 | 1.798957E+02 | 3.291325E+01 | 1.017224E+02 | 5.211890E+02 | -1.059497E-01 |
| 24 | 4.013796E+01 | -7.882894E+01 | 6.327490E+02 | 1.799967E+02 | 2.946670E+01 | 1.024264E+02 | 4.841746E+02 | -1.085450E-01 |
| 25 | 2.974163E+01 | -7.958451E+01 | 4.541575E+02 | 1.799000E+02 | 2.246081E+01 | 1.045621E+02 | 4.073746E+02 | -1.155322E-01 |
| 26 | 2.220733E+01 | -8.476365E+01 | 2.499337E+02 | 1.799308E+02 | 3.517410E+01 | 9.527958E+01 | 3.946662E+02 | -6.944571E-02 |
| 27 | 8.287168E+00 | -8.479611E+01 | 9.347770E+01 | 1.799310E+02 | 2.027338E+01 | 9.522638E+01 | 2.283257E+02 | -6.912818E-02 |
| 28 | 1.557107E-09 | 1.795299E+02 | 1.715721E-10 | 1.470213E+02 | 1.982829E-10 | 1.793414E+02 | 8.908436E-11 | 1.707909E+02 |

TABLE IV (concluded)

| STATION | MAX.MOMENT | MIN.MOMENT | ANG.X-MAJ.AX | PHASE ANGLE | MAX.STRESS | MIN.STRESS |
|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 0. | 0. | 0. |
| 2 | 1.461530E+02 | -1.676295E+01 | -5.020270E+01 | -5.243872E+00 | 2.503978E+01 | -2.871926E+00 |
| 3 | 1.702837E+02 | -1.578333E+01 | -5.020783E+01 | -5.243972E+00 | 9.808943E+01 | -9.091755E+00 |
| 4 | 1.974982E+02 | -1.455684E+01 | -5.021254E+01 | -5.253468E+00 | 2.514620E+02 | -1.853430E+01 |
| 5 | 2.528658E+02 | -1.186812E+01 | -5.021953E+01 | -5.259855E+00 | 3.219580E+02 | -1.511092E+01 |
| 6 | 3.300076E+02 | -7.193476E+00 | -5.022756E+01 | -5.266892E+00 | 4.201778E+02 | -9.158997E+00 |
| 7 | 3.785625E+02 | -3.366614E+00 | -5.023298E+01 | -5.271552E+00 | 4.819996E+02 | -4.286496E+00 |
| 8 | 3.913828E+02 | -2.203116E+00 | -5.023456E+01 | -5.272905E+00 | 3.192544E+02 | -1.797101E+00 |
| 9 | 4.353850E+02 | 2.826449E+00 | -5.024183E+01 | -5.279127E+00 | 3.551474E+02 | 2.305559E+00 |
| 10 | 4.422536E+02 | 3.834118E+00 | -5.024341E+01 | -5.280478E+00 | 3.607501E+02 | 3.127524E+00 |
| 11 | 4.572208E+02 | 6.229819E+00 | -5.024724E+01 | -5.283732E+00 | 8.009828E+01 | 1.091371E+00 |
| 12 | 4.710610E+02 | 9.098688E+00 | -5.025241E+01 | -5.288128E+00 | 1.149496E+02 | 2.220287E+00 |
| 13 | 4.816648E+02 | 1.209516E+01 | -5.025850E+01 | -5.293282E+00 | 1.175372E+02 | 2.951495E+00 |
| 14 | 4.948459E+02 | 1.753957E+01 | -5.027112E+01 | -5.303863E+00 | 1.207537E+02 | 4.280054E+00 |
| 15 | 6.225129E+02 | 1.971040E+01 | -5.004936E+01 | -5.086384E+00 | 1.519073E+02 | 4.809786E+00 |
| 16 | 7.966099E+02 | 2.309324E+01 | -4.985663E+01 | -4.895819E+00 | 1.943909E+02 | 5.635277E+00 |
| 17 | 8.979743E+02 | 2.524099E+01 | -4.977958E+01 | -4.819193E+00 | 2.191262E+02 | 6.159375E+00 |
| 18 | 1.063778E+03 | 2.487502E+01 | -4.953156E+01 | -4.576795E+00 | 2.595861E+02 | 6.070071E+00 |
| 19 | 1.206901E+03 | 2.463595E+01 | -4.937942E+01 | -4.426789E+00 | 2.945113E+02 | 6.011732E+00 |
| 20 | 1.207544E+03 | 2.210428E+01 | -4.914461E+01 | -4.196958E+00 | 2.946681E+02 | 5.393947E+00 |
| 21 | 1.222601E+03 | 1.808546E+01 | -4.878467E+01 | -3.842269E+00 | 1.362389E+02 | 2.015329E+00 |
| 22 | 1.256019E+03 | 1.553911E+01 | -4.858167E+01 | -3.640398E+00 | 1.399628E+02 | 1.731580E+00 |
| 23 | 8.608063E+02 | 1.078510E+01 | -4.853720E+01 | -3.597132E+00 | 7.966630E+01 | 9.981447E-01 |
| 24 | 6.339724E+02 | 7.832114E+00 | -4.856033E+01 | -3.619582E+00 | 2.595647E+01 | 3.206670E-01 |
| 25 | 4.550981E+02 | 5.416666E+00 | -4.868458E+01 | -3.740658E+00 | 1.351481E+01 | 1.608559E-01 |
| 26 | 2.509100E+02 | 2.045452E+00 | -5.005626E+01 | -5.084118E+00 | 1.072363E+01 | 8.742053E-02 |
| 27 | 9.384126E+01 | 7.586343E-01 | -5.004526E+01 | -5.073356E+00 | 6.070321E+00 | 4.907387E-02 |
| 28 | 1.559859E-09 | -1.444334E-10 | 4.841827E+01 | -1.767349E+02 | 1.588855E-08 | -1.471183E-09 |

FORCE TO FOUNDATION AT BEARINGS - RIGID PEDESTALS.

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE |
|---|---|---|---|---|
| 14 | 1.731449E+02 | -5.011756E+00 | -8.593588E+01 | 9.405616E+01 |
| 17 | 6.970316E+01 | -4.229378E+00 | -8.927857E+01 | 9.054761E+01 |
| 19 | 2.429511E+02 | 3.945037E+00 | -8.471486E+01 | -8.469920E+01 |
| 22 | 6.615358E+02 | 4.028102E+00 | -8.671459E+01 | -8.666132E+01 |

ROTOR NO. 1 ENERGY IN= 2.524027E-09 ENERGY OUT= 2.524031E-09

ROTOR NO. 2 ENERGY IN= 0. ENERGY OUT= 0.

BOTH ROTORS- ENERGY IN= 2.524027E-09 ENERGY OUT= 2.524031E-09

## MODIFICATIONS TO CH-47 FORWARD ROTOR-DRIVE GEARBOX LOWER-STAGE PLANETARY SUN GEAR SHAFT AND BEARING SYSTEM

Seven modifications to the lower-stage planetary sun gear shaft and bearing system, shown in Figure 10, have been studied for the purpose of achieving acoustic-frequency vibration reductions. The modifications all include changes to noncritical shaft dimensions (e.g., inner diameters).

Calculations were performed at 1480 Hz and 3390 Hz, the mesh frequencies of the lower-stage planetary sun gear and bevel gears, respectively. Dynamic force levels used to force the shaft at the bevel mesh location were the appropriate components corresponding to the dynamic force levels used for the input spiral bevel pinion shaft vibration response calculations. The following bearing stiffnesses were used in the response calculations, which were performed for 80 percent of maximum gearbox torque. The modifications and their resulting amplitudes are shown in Figures 11 through 17.

| Bearing Number | Fore-Aft (X) Stiffness (lb/in.) | Side-Side (Y) Stiffness (lb/in.) |
|---|---|---|
| 5 | $6.0 \times 10^6$ | $5.6 \times 10^6$ |
| 6 | $2.3 \times 10^6$ | $1.9 \times 10^6$ |
| 7 | $1.8 \times 10^6$ | $1.5 \times 10^6$ |

Of the seven changes considered, Modification No. 7 yields the best reduction of shaft amplitudes.

A summary of the peak dynamic forces in the lower-stage planetary sun gear shaft is presented in Tables V and VI for the seven modifications considered. Table VII shows the weight for each modification analyzed. Sample calculations for Modification No. 7 are shown in Table VIII.

To illustrate the approximate effect upon noise levels of force reductions in the shaft bearings, the force reductions have been converted to db format for the best results obtained (shaft Modification No. 7). The results are presented in Tables IX and X. In these tables, reductions of 8 db are predicted for the lower-stage planetary gear mesh frequency component, and 11 db for the bevel gear mesh frequency component. It should be noted that the information presented in Tables IX and X summarizes the force reductions achieved for both the input bevel gear shaft (bearings 1-4, Modification No. 7) and for the lower-stage planetary sun gear shaft (bearings 5-7, Modification No. 7).

TABLE V. CALCULATED PEAK DYNAMIC BEARING FORCES IN CH-47 LOWER-STAGE PLANETARY SUN GEAR SHAFT BEARINGS AT 1480 HZ

| Modification | Peak Forces (lb) | | |
|---|---|---|---|
| | Bearing 5 | Bearing 6 | Bearing 7 |
| Nominal | 3950 | 1895 | 231 |
| 1 | 4134 | 1657 | 179 |
| 2 | 7822 | 3687 | 536 |
| 3 | 2113 | 965 | 296 |
| 4 | 2241 | 1164 | 134 |
| 5 | 1791 | 915 | 100 |
| 6 | 24,485 | 13,121 | 1810 |
| 7 | 1518 | 759 | 80 |

TABLE VI. CALCULATED PEAK DYNAMIC BEARING FORCES IN CH-47 LOWER-STAGE PLANETARY SUN GEAR SHAFT BEARINGS AT 3390 HZ

| Modification | Peak Forces (lb) | | |
|---|---|---|---|
| | Bearing 5 | Bearing 6 | Bearing 7 |
| Nominal | 207 | 89 | 29 |
| 1 | 391 | 118 | 11 |
| 2 | 146 | 62 | 19 |
| 3 | 11,196 | 3177 | 366 |
| 4 | 127 | 54 | 16 |
| 5 | 130 | 54 | 16 |
| 6 | 133 | 56 | 16 |
| 7 | 140 | 57 | 15 |

| TABLE VII. CALCULATED WEIGHT FOR CH-47 LOWER-STAGE PLANETARY SUN-GEAR SHAFT | |
|---|---|
| Model | Weight (lb) |
| Nominal | 45.9 |
| Modification No. 1 | 82.7 |
| Modification No. 2 | 67.5 |
| Modification No. 3 | 56.7 |
| Modification No. 4 | 77.3 |
| Modification No. 5 | 78.0 |
| Modification No. 6 | 75.9 |
| Modification No. 7 | 78.9 |

TABLE VIII. SAMPLE CALCULATIONS FOR FINAL MODIFICATION FOR CH-47 LOWER-STAGE PLANETARY SUN GEAR SHAFT

CH-47 SUN GEAR SHAFT - MODIFICATION NO. 7

| INTERCONN. | NO.SPEEDS | INPUT | KPT | NBG | BRCH END | IPOS | NINPUT | NGOUT |
|---|---|---|---|---|---|---|---|---|
| 0 | 2 | 1 | 0 | 3 | 0 | 0 | 1 | -0 |

DATA FOR ROTOR NO.1

| STATIONS | BEARINGS | UNBALANCES | RIG/FLEX.PED | BRCH.PT | BRCH.STAT | ST.MATR | NYM | NDST | NSHM |
|---|---|---|---|---|---|---|---|---|---|
| 25 | 3 | 1 | 0 | 27 | 0 | 0 | 1 | 1 | 1 |

| ROTOR DATA STATION | MASS (LB) | POLAR MOM INER. (LB-IN**2) | TRANS MOM INER. (LB-IN**2) | ELEMENT LENGTH (IN) | STIFFNESS O.D. (IN) | MASS O.D. (IN) | STIFF/MASS I.D. (IN) | WEIGHT DENSITY (LB/IN**3) | YOUNGS MOD. (PSI) | (SHP FAC.) *SHEAR MOD. (PSI. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 1.770E+00 | 5.560E+00 | 5.560E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 2 | 0. | 0. | 0. | 3.000E-01 | 4.650E+00 | 4.650E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 3 | 0. | 0. | 0. | 3.753E-01 | 4.650E+00 | 4.650E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 4 | 0. | 0. | 0. | 3.753E-01 | 5.100E+00 | 5.100E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 5 | 0. | 0. | 0. | 3.754E-01 | 5.600E+00 | 5.600E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 6 | 0. | 0. | 0. | 4.500E-01 | 6.456E+00 | 6.456E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 7 | 0. | 0. | 0. | 4.500E-01 | 6.456E+00 | 6.456E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 8 | 0. | 0. | 0. | 4.260E-01 | 6.000E+00 | 6.000E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 9 | 0. | 0. | 0. | 4.260E-01 | 6.000E+00 | 6.000E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 10 | 0. | 0. | 0. | 1.580E-01 | 6.000E+00 | 8.125E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 11 | 1.609E+01 | 4.578E+02 | 2.273E+02 | 1.580E-01 | 6.000E+00 | 8.125E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 12 | 0. | 0. | 0. | 8.765E-01 | 4.650E+00 | 4.650E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 13 | 0. | 0. | 0. | 8.765E-01 | 4.220E+00 | 4.220E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 14 | 0. | 0. | 0. | 8.765E-01 | 3.830E+00 | 3.830E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 15 | 0. | 0. | 0. | 8.765E-01 | 3.545E+00 | 3.545E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 16 | 0. | 0. | 0. | 6.540E-01 | 3.300E+00 | 3.850E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 17 | 2.116E+00 | 1.636E+01 | 8.220E+00 | 7.760E-01 | 3.300E+00 | 3.850E+00 | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 18 | 0. | 0. | 0. | 4.740E-01 | 3.300E+00 | 3.300E+00 | 2.250E+00 | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 19 | 0. | 0. | 0. | 4.700E-01 | 3.080E+00 | 3.300E+00 | 2.250E+00 | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 20 | 0. | 0. | 0. | 4.700E-01 | 3.080E+00 | 3.300E+00 | 2.250E+00 | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 21 | 0. | 0. | 0. | 4.700E-01 | 3.000E+00 | 3.300E+00 | 2.480E+00 | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 22 | 0. | 0. | 0. | 4.700E-01 | 3.000E+00 | 3.300E+00 | 2.480E+00 | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 23 | 0. | 0. | 0. | 4.700E-01 | 2.900E+00 | 3.300E+00 | 2.480E+00 | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 24 | 0. | 0. | 0. | 2.200E-01 | 2.900E+00 | 2.900E+00 | 2.480E+00 | 2.810E-01 | 2.900E+07 | 8.250E+06 |
| 25 | 0. | 0. | 0. | 1.000E+00 | 0. | 0. | 0. | 2.810E-01 | 2.900E+07 | 8.250E+06 |

## TABLE VIII (continued)

BEARING STATIONS
7 20 22

BEARING DATA

BEARING AT STATION 7

| KXX | W*BXX | KXY | W*BXY | KYX | W*BYX | KYY | W*BYY |
|---|---|---|---|---|---|---|---|
| 1.760000E+06 | 1.000000E+00 | 0. | 0. | 0. | 0. | 1.500000E+06 | 1.000000E+00 |
| **CXX** | **W*DXX** | **GXY** | **W*DXY** | **GYX** | **W*DYX** | **GYY** | **W*DYY** |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |

BEARING AT STATION 20

| KXX | W*BXX | KXY | W*BXY | KYX | W*BYX | KYY | W*BYY |
|---|---|---|---|---|---|---|---|
| 2.270000E+06 | 0. | 0. | 0. | 0. | 0. | 1.920000E+06 | 0. |
| **GXX** | **W*DXX** | **GXY** | **W*DXY** | **GYX** | **W*DYX** | **GYY** | **W*DYY** |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |

BEARING AT STATION 22

| KXX | W*BXX | KXY | W*BXY | KYX | W*BYX | KYY | W*BYY |
|---|---|---|---|---|---|---|---|
| 6.000000E+06 | 0. | 0. | 0. | 0. | 0. | 5.550000E+06 | 0. |
| **GXX** | **W*DXX** | **GXY** | **W*DXY** | **GYX** | **W*DYX** | **GYY** | **W*DYY** |
| 0. | 0. | 0. | 0. | 0. | 0. | 0. | 0. |

CUMULATIVE DATA FOR ROTOR NO. 1

| STATION | CUM.LENGTH | ELEMENT WEIGHT | CUM.WEIGHT |
|---|---|---|---|
| 1 | 0.00000 | 12.0759 | 0.0000 |
| 2 | 1.77000 | 1.4316 | 12.0759 |
| 3 | 2.07000 | 1.7409 | 13.5075 |
| 4 | 2.44530 | 2.1543 | 15.2984 |
| 5 | 2.82060 | 2.5982 | 17.4528 |
| 6 | 3.19600 | 4.1396 | 20.0509 |
| 7 | 3.64600 | 4.1394 | 24.1906 |
| 8 | 4.09600 | 3.3846 | 28.3300 |
| 9 | 4.52200 | 3.3846 | 31.7146 |
| 10 | 4.94800 | 2.3017 | 35.0992 |
| 11 | 5.10600 | 18.3887 | 53.4879 |
| 12 | 5.26400 | 4.1827 | 55.7896 |
| 13 | 6.14050 | 3.4449 | 59.9722 |
| 14 | 7.01700 | 2.4376 | 63.4171 |
| 15 | 7.89350 | 2.4314 | 66.2547 |
| 16 | 8.77000 | 2.1394 | 68.6861 |
| 17 | 9.42400 | 4.6545 | 72.9415 |
| 18 | 10.20000 | .6096 | 75.4800 |
| 19 | 10.67400 | .6045 | 76.0896 |
| 20 | 11.14400 | .6045 | 76.6941 |
| 21 | 11.61400 | .4916 | 77.2985 |
| 22 | 12.08400 | .4916 | 77.7902 |
| 23 | 12.55400 | .4916 | 78.2818 |
| 24 | 13.02400 | .1147 | 78.7734 |
| 25 | 13.25400 | 0.0000 | 78.8881 |

TOTAL SYSTEM WEIGHT= 78.8881

| FIRST SPEED | LAST SPEED | SPEED INCR. | FREQUENCY | FREQ/SPEED | DAMPING FACTOR |
|---|---|---|---|---|---|
| 3.970000E+03 | 1.000000E+02 | 1.000000E+02 | 3.390000E+03 | -0. | 1.000000E+00 |

FORCE EXCITATION DATA FOR ROTOR 1

| STATION | F-X,COS.COMP | F-X,SIN.COMP | F-Y,COS.COMP | F-Y,SIN.COMP |
|---|---|---|---|---|
| 11 | 5.311900E+02 | 0. | 8.746300E+02 | -0. |

# TABLE VIII (continued)

ROTOR SPEED= 3.970000E+03 RPM

EXCITATION FREQUENCY= 3.390000E+03 CPS

AMPLITUDES FOR ROTOR NO. 1

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE | X-AMPLITUDE | X-PHASE ANGLE | Y-AMPLITUDE | Y-PHASE ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.351341E-05 | -9.021186E-08 | 5.008299E+01 | 2.401141E+02 | 6.740201E-06 | 1.793664E+02 | 1.171282E-05 | 2.702512E+02 |
| 2 | 1.208964E-05 | -5.495549E-08 | 5.930281E+01 | 2.393218E+02 | 6.171950E-06 | 1.795803E+02 | 1.039564E-05 | 2.701736E+02 |
| 3 | 1.160290E-05 | -4.766757E-08 | 5.914245E+01 | 2.391598E+02 | 5.951259E-06 | 1.796229E+02 | 9.960522E-06 | 2.701575E+02 |
| 4 | 1.097911E-05 | -3.856608E-08 | 5.892517E+01 | 2.389395E+02 | 5.667042E-06 | 1.796803E+02 | 9.463562E-06 | 2.701356E+02 |
| 5 | 1.044977E-05 | -3.010419E-08 | 5.869437E+01 | 2.387042E+02 | 5.429795E-06 | 1.797404E+02 | 8.920383E-06 | 2.701122E+02 |
| 6 | 1.000617E-05 | -2.225513E-08 | 5.845389E+01 | 2.384634E+02 | 5.235107E-06 | 1.798022E+02 | 8.527459E-06 | 2.700877E+02 |
| 7 | 9.606785E-06 | -1.367174E-08 | 5.816234E+01 | 2.381696E+02 | 5.067730E-06 | 1.798759E+02 | 8.161410E-06 | 2.700579E+02 |
| 8 | 9.207006E-06 | -5.309725E-09 | 5.784199E+01 | 2.378472E+02 | 4.900486E-06 | 1.799527E+02 | 7.794499E-06 | 2.700260E+02 |
| 9 | 8.739454E-06 | 2.664033E-09 | 5.750694E+01 | 2.375107E+02 | 4.694814E-06 | 1.800312E+02 | 7.371349E-06 | 2.699926E+02 |
| 10 | 8.302368E-06 | 1.015937E-08 | 5.715784E+01 | 2.371607E+02 | 4.502603E-06 | 1.801115E+02 | 6.975384E-06 | 2.699576E+02 |
| 11 | 8.148668E-06 | 1.278928E-08 | 5.702852E+01 | 2.370292E+02 | 4.434932E-06 | 1.801413E+02 | 6.836106E-06 | 2.699443E+02 |
| 12 | 8.582492E-06 | 1.520875E-08 | 5.704195E+01 | 2.370440E+02 | 4.669106E-06 | 1.801587E+02 | 7.201309E-06 | 2.699363E+02 |
| 13 | 1.224580E-05 | 3.204184E-08 | 5.743903E+01 | 2.374361E+02 | 6.590707E-06 | 1.802318E+02 | 1.032101E-05 | 2.699013E+02 |
| 14 | 1.675085E-05 | 5.031839E-09 | 5.791313E+01 | 2.379051E+02 | 8.898277E-06 | 1.802604E+02 | 1.419207E-05 | 2.698840E+02 |
| 15 | 2.175790E-05 | 6.821989E-08 | 5.839216E+01 | 2.383793E+02 | 1.140352E-05 | 1.802790E+02 | 1.853027E-05 | 2.698766E+02 |
| 16 | 2.658982E-05 | 8.273145E-08 | 5.885836E+01 | 2.388410E+02 | 1.375125E-05 | 1.802 77E+02 | 2.275805E-05 | 2.698749E+02 |
| 17 | 2.953490E-05 | 8.905810E-08 | 5.921064E+01 | 2.391900E+02 | 1.511861E-05 | 1.802693E+02 | 2.537214E-05 | 2.698764E+02 |
| 18 | 3.074855E-05 | 8.829114E-08 | 5.964350E+01 | 2.396190E+02 | 1.553985E-05 | 1.802504E+02 | 2.653289E-05 | 2.698791E+02 |
| 19 | 3.020859E-05 | 8.418939E-08 | 6.000083E+01 | 2.399736E+02 | 1.510469E-05 | 1.802494E+02 | 2.616166E-05 | 2.698608E+02 |
| 20 | 2.843208E-05 | 7.663651E-08 | 6.048926E+01 | 2.404548E+02 | 1.400542E-05 | 1.802423E+02 | 2.474342E-05 | 2.698821E+02 |
| 21 | 2.713386E-05 | 7.058630E-08 | 6.095022E+01 | 2.408569E+02 | 1.320034E-05 | 1.802344E+02 | 2.370658E-05 | 2.698837E+02 |
| 22 | 2.473185E-05 | 6.156472E-08 | 6.143039E+01 | 2.413935E+02 | 1.182754E-05 | 1.802251E+02 | 2.172044E-05 | 2.698855E+02 |
| 23 | 2.554443E-05 | 6.089119E-08 | 6.174204E+01 | 2.417028E+02 | 1.209393E-05 | 1.802149E+02 | 2.258019E-05 | 2.698874E+02 |
| 24 | 2.607947E-05 | 5.953715E-08 | 6.203852E+01 | 2.419971E+02 | 1.222820E-05 | 1.802050E+02 | 2.303505E-05 | 2.698892E+02 |
| 25 | 2.619807E-05 | 5.854047E-08 | 6.218038E+01 | 2.421340E+02 | 1.222647E-05 | 1.802002E+02 | 2.317015E-05 | 2.698900E+02 |

| STATION | X MOM-AMPL | X MOM-ANGLE | Y MOM-AMPL | Y MOM-ANGLE | X SHR-AMPL | X SHR-ANGLE | Y SHR-AMPL | Y SHR-ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 9.000000E+01 | 0. | 0. | 0. | 9.000000E+01 |
| 2 | 8.307740E+01 | -8.943390E+01 | 1.429683E+02 | -2.272405E-01 | 9.251932E+01 | -8.946870E+01 | 1.584111E+02 | -2.144983E-01 |
| 3 | 1.123720E+02 | -8.944469E+01 | 1.930787E+02 | -2.233648E-01 | 1.027173E+02 | -8.948106E+01 | 1.755362E+02 | -2.099210E-01 |
| 4 | 1.532349E+02 | -8.945701E+01 | 2.628180E+02 | -2.189242E-01 | 1.149442E+02 | -8.949905E+01 | 1.959144E+02 | -2.033604E-01 |
| 5 | 1.990283E+02 | -8.946954E+01 | 3.407371E+02 | -2.143939E-01 | 1.299921E+02 | -8.952272E+01 | 2.191213E+02 | -1.949726E-01 |
| 6 | 2.505268E+02 | -8.948339E+01 | 4.280360E+02 | -2.093645E-01 | 1.452751E+02 | -8.955053E+01 | 2.457724E+02 | -1.846559E-01 |
| 7 | 3.215713E+02 | -8.950309E+01 | 5.478364E+02 | -2.021777E-01 | 1.614234E+02 | -8.957728E+01 | 2.741348E+02 | -1.730237E-01 |
| 8 | 3.996982E+02 | -8.952203E+01 | 6.799472E+02 | -1.950321E-01 | 1.856722E+02 | -8.962124E+01 | 3.129487E+02 | -1.575026E-01 |
| 9 | 4.828873E+02 | -8.954215E+01 | 8.197959E+02 | -1.875067E-01 | 2.047533E+02 | -8.965573E+01 | 3.431030E+02 | -1.445000E-01 |
| 10 | 5.740330E+02 | -8.956793E+01 | 9.720883E+02 | -1.797404E-01 | 2.230358E+02 | -8.968978E+01 | 3.716225E+02 | -1.315302E-01 |
| 11 | 4.554922E+02 | -9.018216E+01 | 8.109538E+02 | 9.435774E-02 | 2.122317E+02 | 8.973699E+01 | 3.550962E+02 | 1.801140E+02 |
| 12 | 4.229240E+02 | -9.017567E+01 | 7.653354E+02 | 9.278645E-02 | 1.999180E+02 | 8.973005E+01 | 3.361113E+02 | 1.801179E+02 |
| 13 | 2.590525E+02 | -9.011250E+01 | 4.884030E+02 | 7.710413E-02 | 1.723357E+02 | 8.971914E+01 | 2.932326E+02 | 1.801228E+02 |
| 14 | 1.210856E+02 | -8.991690E+01 | 2.519461E+02 | 3.280444E-02 | 1.410115E+02 | 8.971282E+01 | 2.436982E+02 | 1.801257E+02 |
| 15 | 1.175416E+01 | -8.645179E+01 | 6.121130E+01 | -2.589736E-01 | 1.071200E+02 | 8.970878E+01 | 1.891066E+02 | 1.801272E+02 |
| 16 | 6.685798E+01 | 8.903140E+01 | 7.950557E+01 | 1.804253E+02 | 7.106582E+01 | 8.970274E+01 | 1.299578E+02 | 1.801283E+02 |
| 17 | 1.128056E+02 | 8.977534E+01 | 1.675430E+02 | 1.801141E+02 | 2.936832E+00 | 8.965815E+01 | 6.184181E+00 | 1.802133E+02 |
| 18 | 9.277948E+01 | 8.976891E+01 | 1.423888E+02 | 1.801157E+02 | 4.888597E+01 | -9.022508E+01 | 7.159140E+01 | 1.143240E-01 |
| 19 | 6.698985E+01 | 8.976601E+01 | 1.039642E+02 | 1.801159E+02 | 5.987891E+01 | -9.023085E+01 | 9.049314E+01 | 1.155342E-01 |
| 20 | 3.638181E+01 | 8.976815E+01 | 5.713627E+01 | 1.801160E+02 | 3.844549E+01 | -9.022542E+01 | 6.109916E+01 | 1.146089E-01 |
| 21 | 1.601573E+01 | 8.976202E+01 | 2.434081E+01 | 1.801175E+02 | 4.812323E+01 | -9.022804E+01 | 7.833301E+01 | 1.151651E-01 |
| 22 | 8.334540E+00 | -9.020967E+01 | 1.560847E+01 | 1.114027E-01 | 1.560265E+01 | 8.978043E+01 | 2.907603E+01 | 1.801124E+02 |
| 23 | 2.620927E+00 | -9.020612E+01 | 4.930236E+00 | 1.110430E-01 | 8.694909E+00 | 8.979140E+01 | 1.628009E+01 | 1.801115E+02 |
| 24 | 1.395596E-01 | -9.020180E+01 | 3.583155E-01 | 1.102698E-01 | 1.648383E-00 | 8.979790E+01 | 3.114491E+00 | 1.801104E+02 |
| 25 | 3.450179E-10 | -8.990088E+01 | 2.447134E-11 | 1.875542E+02 | 1.651777E-11 | 9.079409E+01 | 2.927888E-11 | 1.801474E+02 |

## TABLE VIII (continued)

| STATION | MAX.MOMENT | MIN.MOMENT | ANG.X-MAJ.AX | PHASE ANGLE | MAX.STRESS | MIN.STRESS |
|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 0. | 0. | 0. |
| 2 | 1.653505E+02 | -9.945842E-01 | -1.484075E+01 | -1.498677E+02 | 1.675119E+01 | -1.007585E-01 |
| 3 | 2.233945E+02 | -1.319901E+00 | -1.480168E+01 | -1.498280E+02 | 2.263147E+01 | -1.337154E-01 |
| 4 | 3.042222E+02 | -1.760323E+00 | -1.475695E+01 | -1.497826E+02 | 2.336036E+01 | -1.351702E-01 |
| 5 | 3.945999E+02 | -2.234169E+00 | -1.471137E+01 | -1.497363E+02 | 2.288716E+01 | -1.295839E-01 |
| 6 | 4.959547E+02 | -2.739561E+00 | -1.466081E+01 | -1.496849E+02 | 1.877198E+01 | -1.036929E-01 |
| 7 | 6.352333E+02 | -3.383733E+00 | -1.458865E+01 | -1.496117E+02 | 2.404371E+01 | -1.260750E-01 |
| 8 | 7.887575E+02 | -4.047414E+00 | -1.455408E+01 | -1.495763E+02 | 3.719537E+01 | -1.909636E-01 |
| 9 | 9.514324E+02 | -4.686417E+00 | -1.450126E+01 | -1.495225E+02 | 4.436661E+01 | -2.205970E-01 |
| 10 | 1.128912E+03 | -5.321105E+00 | -1.443820E+01 | -1.494585E+02 | 5.323598E+01 | -2.509269E-01 |
| 11 | 9.379732E+02 | 1.921657E+00 | -1.594756E+01 | -1.509184E+02 | 4.423192E+01 | 9.061942E-02 |
| 12 | 8.744141E+02 | 1.734393E+00 | -1.607512E+01 | -1.510451E+02 | 8.858443E+01 | 1.757064E-01 |
| 13 | 5.528705E+02 | 7.574010E-01 | -1.705461E+01 | -1.520191E+02 | 7.493508E+01 | 1.026568E-01 |
| 14 | 2.795327E+02 | -9.581032E-02 | -1.933101E+01 | -1.542888E+02 | 5.067986E+01 | -1.737061E-02 |
| 15 | 6.232492E+01 | -7.665191E-01 | -3.415180E+01 | -1.692757E+02 | 1.424629E+01 | -1.752117E-01 |
| 16 | 1.038729E+02 | 1.244685E+00 | -4.940216E+00 | 3.990781E+01 | 2.944147E+01 | 3.527904E-01 |
| 17 | 2.019789E+02 | 5.533234E-01 | -1.104806E+01 | 3.396041E+01 | 5.724838E+01 | 1.568326E-01 |
| 18 | 1.699482E+02 | 4.704906E-01 | -1.191223E+01 | 3.310012E+01 | 6.144952E+01 | 1.701191E-01 |
| 19 | 1.236773E+02 | 3.419646E-01 | -1.220429E+01 | 3.280957E+01 | 6.825308E+01 | 1.887202E-01 |
| 20 | 9.773592E+01 | 1.863317E-01 | -1.251305E+01 | 3.250262E+01 | 3.738146E+01 | 1.028310E-01 |
| 21 | 2.913713E+01 | 8.308279E-02 | -1.165614E+01 | 3.335394E+01 | 2.062334E+01 | 5.874962E-02 |
| 22 | 1.769427E+01 | 4.123441E-02 | -1.689908E+01 | -1.518587E+02 | 1.252405E+01 | 2.918583E-02 |
| 23 | 5.583576E+00 | 1.281063E-02 | -1.700497E+01 | -1.519638E+02 | 5.013080E+00 | 1.150172E-02 |
| 24 | 4.055433E-01 | 9.127247E-04 | -1.713323E+01 | -1.520911E+02 | 3.641074E-01 | 8.194681E-04 |
| 25 | 3.458701E-10 | -3.167325E-12 | 4.902322E+01 | -8.584076E+01 | 0. | 0. |

FORCE TO FOUNDATION AT BEARINGS - RIGID PEDESTALS.

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE |
|---|---|---|---|---|
| 7 | 1.514665E+01 | -2.289300E-02 | 5.392419E+01 | 5.391900E+01 |
| 20 | 5.716357E+01 | 1.661315E-01 | 5.620945E+01 | 5.620297E+01 |
| 22 | 1.398852E+02 | 3.624608E-01 | 5.951546E+01 | 5.948833E+01 |

ROTOR NO. 1 ENERGY IN= 2.899392E-10 ENERGY OUT= 2.899392E-10

ROTOR NO. 2 ENERGY IN= 0. ENERGY OUT= 0.

BOTH ROTORS ENERGY IN= 2.899392E-10 ENERGY OUT= 2.899392E-10

| FIRST SPEED | LAST SPEED | SPEED INCR. | FREQUENCY | FREQ/SPEED | DAMPING FACTOR |
|---|---|---|---|---|---|
| 3.970000E+03 | 1.000000E+02 | 1.000000E+02 | 1.480000E+03 | -0. | 1.000000E+00 |

FORCE EXCITATION DATA FOR ROTOR 1

| STATION | F-X.COS.COMP | F-X.SIN.COMP | F-Y.COS.COMP | F-Y.SIN.COMP |
|---|---|---|---|---|
| 11 | 1.611400E+02 | 0. | 2.653200E+02 | 0. |

# TABLE VIII (continued)

ROTOR SPEED= 3.970000E+03 RPM

EXCITATION FREQUENCY= 1.480000E+03 CPS

AMPLITUDES FOR ROTOR NO. 1

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE | X-AMPLITUDE | X-PHASE ANGLE | Y-AMPLITUDE | Y-PHASE ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 3.625318E-04 | -1.074574E-04 | 1.448533E+02 | 2.023482E+02 | 3.036226E-04 | 2.356958E+02 | 1.982433E-04 | 1.452348E+02 |
| 2 | 1.451837E-04 | 1.074833E-05 | 1.487476E+02 | 2.041812E+02 | 1.405350E-04 | 2.331110E+02 | 8.558481E-05 | 1.515803E+02 |
| 3 | 1.297542E-04 | 1.277414E-05 | 1.447247E+02 | 2.049749E+02 | 1.122424E-04 | 2.319599E+02 | 6.634060E-05 | 1.548256E+02 |
| 4 | 8.482551E-05 | 1.521594E-05 | 1.520147E+02 | 2.066738E+02 | 7.701079E-05 | 2.293303E+02 | 4.289757E-05 | 1.629006E+02 |
| 5 | 4.487552E-05 | 1.738343E-05 | 1.400791E+02 | 2.105323E+02 | 4.260045E-05 | 2.224716E+02 | 2.430777E-05 | 1.873246E+02 |
| 6 | 2.250411E-05 | 1.582110E-06 | 5.525120E+01 | 2.269343E+02 | 1.285542E-05 | 1.774000E+02 | 1.451678E-05 | 2.508917E+02 |
| 7 | 4.987323E-05 | -2.234926E-05 | 1.302492E+02 | 3.578309E+02 | 3.642614E-05 | 7.563420E+01 | 4.074812E-05 | 2.969326E+02 |
| 8 | 4.885774E-05 | -2.595519E-05 | 1.349250E+02 | 1.273286E+01 | 7.844301E-05 | 6.617320E+01 | 6.702623E-05 | 3.065742E+02 |
| 9 | 1.455366E-04 | -2.475144E-05 | 1.411238E+02 | 1.541171E+01 | 1.140097E-04 | 6.334301E+01 | 9.411538E-05 | 3.105100E+02 |
| 10 | 1.920277E-04 | -3.154469E-05 | 1.421749E+02 | 1.644129E+01 | 1.529122E-04 | 6.194449E+01 | 1.203759E-04 | 3.127034E+02 |
| 11 | 2.090874E-04 | -3.241028E-05 | 1.424381E+02 | 1.719912E+01 | 1.667291E-04 | 6.159072E+01 | 1.300573E-04 | 3.132067E+02 |
| 12 | 2.254555E-04 | -3.770646E-05 | 1.426268E+02 | 1.743628E+01 | 1.803051E-04 | 6.132295E+01 | 1.394731E-04 | 3.137360E+02 |
| 13 | 3.044404E-04 | -3.524474E-05 | 1.432253E+02 | 1.820749E+01 | 2.490038E-04 | 6.039006E+01 | 1.879247E-04 | 3.153510E+02 |
| 14 | 3.791157E-04 | -4.354731E-05 | 1.434738E+02 | 1.852276E+01 | 3.057563E-04 | 5.991402E+01 | 2.283404E-04 | 3.162297E+02 |
| 15 | 4.291474E-04 | -4.622444E-05 | 1.435501E+02 | 1.862237E+01 | 3.463022E-04 | 5.961943E+01 | 2.576717E-04 | 3.167700E+02 |
| 16 | 4.550414E-04 | -4.675074E-05 | 1.435119E+02 | 1.258228E+01 | 3.669007E-04 | 5.941590E+01 | 2.731926E-04 | 3.171624E+02 |
| 17 | 4.560407E-04 | -4.555455E-05 | 1.434151E+02 | 1.847070E+01 | 3.671944E-04 | 5.929001E+01 | 2.742565E-04 | 3.173909E+02 |
| 18 | 4.358825E-04 | -4.230287E-05 | 1.432350E+02 | 1.824129E+01 | 3.509059E-04 | 5.916404E+01 | 2.630743E-04 | 3.176429E+02 |
| 19 | 4.053702E-04 | -3.857778E-05 | 1.430182E+02 | 1.800718E+01 | 3.260509E-04 | 5.908817E+01 | 2.457949E-04 | 3.177865E+02 |
| 20 | 3.557225E-04 | -3.324407E-05 | 1.426474E+02 | 1.757198E+01 | 2.834893E-04 | 5.900700E+01 | 2.174377E-04 | 3.179300E+02 |
| 21 | 3.153754E-04 | -2.874477E-05 | 1.423542E+02 | 1.723119E+01 | 2.503335E-04 | 5.890579E+01 | 1.939689E-04 | 3.181260E+02 |
| 22 | 2.621230E-04 | -2.314147E-05 | 1.418709E+02 | 1.667040E+01 | 2.046843E-04 | 5.877211E+01 | 1.628684E-04 | 3.183682E+02 |
| 23 | 2.467070E-04 | -2.088481E-05 | 1.415935E+02 | 1.635637E+01 | 1.937598E-04 | 5.859920E+01 | 1.541330E-04 | 3.186729E+02 |
| 24 | 2.307722E-04 | -1.849480E-05 | 1.412790E+02 | 1.600269E+01 | 1.804283E-04 | 5.840113E+01 | 1.450743E-04 | 3.190130E+02 |
| 25 | 2.227301E-04 | -1.731555E-05 | 1.411087E+02 | 1.581230E+01 | 1.737000E-04 | 5.829292E+01 | 1.494844E-04 | 3.191973E+02 |

| STATION | X MOM-AMPL | X MOM-ANGLE | Y MOM-AMPL | Y MOM-ANGLE | X SHR-AMPL | X SHR-ANGLE | Y SHR-AMPL | Y SHR-ANGLE |
|---|---|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 9.000000E+01 | 0. | 0. | 0. | 9.000000E+01 |
| 2 | 5.975504E+02 | -1.451366E+02 | 3.950173E+02 | 1.234375E+02 | 6.016576E+02 | -1.448106E+02 | 3.841090E+02 | 1.220506E+02 |
| 3 | 7.843803E+02 | -1.450440E+02 | 5.640280E+02 | 1.234114E+02 | 6.421545E+02 | -1.446767E+02 | 4.083379E+02 | 1.225022E+02 |
| 4 | 1.032531E+03 | -1.444304E+02 | 6.615931E+02 | 1.231333E+02 | 6.800226E+02 | -1.444056E+02 | 4.290462E+02 | 1.219711E+02 |
| 5 | 1.294015E+03 | -1.443068E+02 | 8.258949E+02 | 1.228262E+02 | 7.045898E+02 | -1.441500E+02 | 4.440639E+02 | 1.211871E+02 |
| 6 | 1.563246E+03 | -1.444577E+02 | 9.935439E+02 | 1.224554E+02 | 7.228073E+02 | -1.437189E+02 | 4.473956E+02 | 1.200199E+02 |
| 7 | 1.887134E+03 | -1.444212E+02 | 1.191376E+03 | 1.218585E+02 | 7.790286E+02 | -1.444529E+02 | 4.802342E+02 | 1.217906E+02 |
| 8 | 2.223714E+03 | -1.443827E+02 | 1.398254E+03 | 1.216578E+02 | 7.136385E+02 | -1.436078E+02 | 4.353709E+02 | 1.189816E+02 |
| 9 | 2.516096E+03 | -1.442276E+02 | 1.571966E+03 | 1.211869E+02 | 6.405860E+02 | -1.424006E+02 | 3.792432E+02 | 1.154035E+02 |
| 10 | 2.771914E+03 | -1.439822E+02 | 1.717085E+03 | 1.204849E+02 | 5.489627E+02 | -1.405347E+02 | 3.056977E+02 | 1.095790E+02 |
| 11 | 7.295274E+03 | -1.484936E+02 | 4.874220E+03 | 1.310127E+02 | 2.247631E+02 | 3.768190E+01 | 7.981508E+01 | -7.510626E+01 |
| 12 | 7.252594E+03 | -1.485209E+02 | 4.859500E+03 | 1.310720E+02 | 3.134794E+02 | 3.508362E+01 | 1.436090E+02 | -6.843465E+01 |
| 13 | 6.845095E+03 | -1.486351E+02 | 4.672220E+03 | 1.313140E+02 | 5.144958E+02 | 3.274779E+01 | 2.947350E+02 | -5.220416E+01 |
| 14 | 6.353181E+03 | -1.487136E+02 | 4.346157E+03 | 1.314650E+02 | 7.293556E+02 | 3.192943E+01 | 4.552429E+02 | -5.000764E+01 |
| 15 | 5.624635E+03 | -1.487694E+02 | 3.880721E+03 | 1.316028E+02 | 9.373993E+02 | 3.155617E+01 | 6.101016E+02 | -4.512363E+01 |
| 16 | 4.718341E+03 | -1.488121E+02 | 3.283026E+03 | 1.316927E+02 | 1.132473E+03 | 3.137223E+01 | 7.551995E+02 | -4.871192E+01 |
| 17 | 3.937726E+03 | -1.488247E+02 | 2.760769E+03 | 1.317145E+02 | 1.482877E+03 | 3.128734E+01 | 1.016650E+03 | -4.835770E+01 |
| 18 | 2.706415E+03 | -1.488256E+02 | 1.911442E+03 | 1.317217E+02 | 1.687694E+03 | 3.115421E+01 | 1.170044E+03 | -4.824734E+01 |
| 19 | 1.855490E+03 | -1.488153E+02 | 1.348493E+03 | 1.317053E+02 | 1.733866E+03 | 3.114672E+01 | 1.204462E+03 | -4.823108E+01 |
| 20 | 1.071867E+03 | -1.487841E+02 | 7.746799E+02 | 1.318550E+02 | 1.131573E+03 | 3.122730E+01 | 8.187875E+02 | -4.636708E+01 |
| 21 | 5.305515E+02 | -1.487924E+02 | 3.831748E+02 | 1.316710E+02 | 1.147744E+03 | 3.122151E+01 | 5.466618E+02 | -4.835590E+01 |
| 22 | 2.439329E+01 | 3.150109E+01 | 1.951076E+01 | -4.888619E+01 | 4.720921E+01 | -1.465750E+02 | 3.760365E+01 | 1.312856E+02 |
| 23 | 7.443084E+00 | 3.157458E+01 | 5.977056E+00 | -4.897234E+01 | 2.515460E+01 | -1.484734E+02 | 2.014679E+01 | 1.311137E+02 |
| 24 | 5.198177E-01 | 3.147009E+01 | 4.195911E-01 | -4.913440E+01 | 4.548926E+00 | -1.483481E+02 | 3.666254E+00 | 1.308959E+02 |
| 25 | 2.787130E-10 | 1.608555E+02 | 2.537097E-10 | 2.524528E+02 | 1.225221E-10 | 7.183404E+01 | 1.865093E-10 | 1.663685E+02 |

TABLE VIII (concluded)

| STATION | MAX.MOMENT | MIN.MOMENT | ANG.X-MAJ.AX | PHASE ANGLE | MAX.STRESS | MIN.STRESS |
|---|---|---|---|---|---|---|
| 1 | 0. | 0. | 0. | 0. | 0. | 0. |
| 2 | 7.108479E+02 | 6.924767E+00 | 7.779052E+01 | -1.127057E+02 | 7.201399E+01 | 7.015287E-01 |
| 3 | 9.322958E+02 | 1.143052E+01 | 7.771990E+01 | -1.127755E+02 | 9.444825E+01 | 1.157994E+00 |
| 4 | 1.226498E+03 | 1.882193E+01 | 7.763339E+01 | -1.128605E+02 | 9.417927E+01 | 1.445282E+00 |
| 5 | 1.534849E+03 | 2.875748E+01 | 7.753830E+01 | -1.129533E+02 | 8.902268E+01 | 1.667961E+00 |
| 6 | 1.851820E+03 | 4.225547E+01 | 7.742378E+01 | -1.130643E+02 | 7.009175E+01 | 1.599378E+00 |
| 7 | 2.230779E+03 | 6.539592E+01 | 7.724136E+01 | -1.132391E+02 | 8.443545E+01 | 2.475248E+00 |
| 8 | 2.625515E+03 | 8.178626E+01 | 7.713460E+01 | -1.133685E+02 | 1.238112E+02 | 3.856787E+00 |
| 9 | 2.964868E+03 | 1.066509E+02 | 7.695942E+01 | -1.135538E+02 | 1.398140E+02 | 5.029326E+00 |
| 10 | 3.257571E+03 | 1.408674E+02 | 7.672187E+01 | -1.137915E+02 | 1.536170E+02 | 6.642869E+00 |
| 11 | 8.749149E+03 | -6.715114E+02 | 7.861844E+01 | -1.119539E+02 | 4.125828E+02 | -3.166640E+01 |
| 12 | 8.704329E+03 | -6.747898E+02 | 7.867942E+01 | -1.118841E+02 | 8.818110E+02 | -6.836105E+01 |
| 13 | 8.301935E+03 | -6.707073E+02 | 7.897178E+01 | -1.115474E+02 | 1.125229E+03 | -9.090646E+01 |
| 14 | 7.671100E+03 | -6.373237E+02 | 7.922066E+01 | -1.112588E+02 | 1.390786E+03 | -1.155481E+02 |
| 15 | 6.809068E+03 | -5.771541E+02 | 7.944615E+01 | -1.109959E+02 | 1.556424E+03 | -1.319264E+02 |
| 16 | 5.726937E+03 | -4.931431E+02 | 7.967140E+01 | -1.107321E+02 | 1.623229E+03 | -1.397752E+02 |
| 17 | 4.790876E+03 | -4.150434E+02 | 7.987237E+01 | -1.104974E+02 | 1.357914E+03 | -1.176389E+02 |
| 18 | 3.301339E+03 | -2.868895E+02 | 8.007198E+01 | -1.102623E+02 | 1.193691E+03 | -1.037329E+02 |
| 19 | 2.317816E+03 | -2.013996E+02 | 8.027164E+01 | -1.100268E+02 | 1.279134E+03 | -1.111465E+02 |
| 20 | 1.316921E+03 | -1.141594E+02 | 8.073429E+01 | -1.094809E+02 | 7.267699E+02 | -6.300122E+01 |
| 21 | 6.519980E+02 | -5.662535E+01 | 8.069322E+01 | -1.095290E+02 | 4.614861E+02 | -4.007959E+01 |
| 22 | 3.113087E+01 | -2.563445E+00 | 8.356616E+01 | 7.382361E+01 | 2.203452E+01 | -1.814414E+00 |
| 23 | 9.514989E+00 | -7.679107E-01 | 8.368259E+01 | 7.395431E+01 | 8.542806E+00 | -6.894503E-01 |
| 24 | 6.659791E-01 | -5.233414E-02 | 8.383322E+01 | 7.412284E+01 | 5.979334E-01 | -4.698695E-02 |
| 25 | 3.768487E-10 | 5.884996E-12 | 2.690031E+00 | 1.193600E+02 | 0. | 0. |

FORCE TO FOUNDATION AT BEARINGS - RIGID PEDESTALS.

| STATION | MAJOR AXIS | MINOR AXIS | ANGLE X-MAJ.AX | PHASE ANGLE |
|---|---|---|---|---|
| 7 | 8.072131E+01 | -3.647037E+01 | -4.293117E+01 | -1.700941E+02 |
| 20 | 7.641021E+02 | -6.750372E+01 | -3.277177E+01 | -1.570192E+02 |
| 22 | 1.528877E+03 | -1.324063E+02 | -3.594874E+01 | -1.607703E+02 |

ROTOR NO. 1 ENERGY IN= 9.384805E-09 ENERGY OUT= 9.384800E-09

ROTOR NO. 2 ENERGY IN= 0. ENERGY OUT= 0.

BOTH ROTORS ENERGY IN= 9.384805E-09 ENERGY OUT= 9.384800E-09

TABLE IX. PREDICTED BEARING PEAK DYNAMIC FORCE REDUCTIONS IN db FORMAT AT 1480 HZ

| Bearing | Peak Dynamic Force (lb) (Nom. Config.) | db (re. 1.0 lb) (Nom. Config.) | Peak Dynamic Force (lb) (Mod. Config.) | db (re. 1.0 lb) (Mod. Config.) |
|---|---|---|---|---|
| 1 | 336 | 50.0 | 173 | 44.8 |
| 2 | 20 | 26.0 | 70 | 36.9 |
| 3 | 131 | 42.3 | 243 | 47.7 |
| 4 | 1587 | 63.8 | 662 | 56.4 |
| 5 | 3950 | 71.9 | 1518 | 63.4 |
| 6 | 1895 | 65.6 | 759 | 57.6 |
| 7 | 231 | 47.3 | 80 | 38.1 |
| Log Sum | | 73.3 | | 65.0 |

$\Delta$ db = 73.3 - 65.0 = 8.3 db

TABLE X. PREDICTED BEARING PEAK DYNAMIC FORCE REDUCTIONS IN db FORMAT AT 3390 HZ

| Bearing | Peak Dynamic Force (lb) (Nom. Config.) | db (re. 1.0 lb) (Nom. Config.) | Peak Dynamic Force (lb) (Mod. Config.) | db (re. 1.0 lb) (Mod. Config.) |
|---|---|---|---|---|
| 1 | 350 | 50.8 | 15 | 23.5 |
| 2 | 226 | 47.1 | 52 | 34.3 |
| 3 | 276 | 48.8 | 127 | 42.1 |
| 4 | 719 | 57.1 | 187 | 45.4 |
| 5 | 207 | 46.3 | 139 | 42.9 |
| 6 | 89 | 39.0 | 57 | 35.1 |
| 7 | 29 | 39.2 | 15 | 23.5 |
| Log Sum | | 59.4 | | 48.3 |

$\Delta$ db = 59.4 - 48.3 = 11.1 db

## MODIFICATIONS TO CH-47 FORWARD ROTOR-DRIVE RING-GEAR STRUCTURAL COMPONENTS

Ten conceptual modifications to the ring gear were considered as a preliminary step in this portion of the study. In each modification, the attempt was made to isolate the gearbox casing, through ring-gear component flexibility, from gear mesh frequency dynamic forces arising at the lower ring gear. A number of the concepts were judged to be unsuitable for reasons of manufacturing difficulty or unnecessary complexity. Three of the ten modifications were considered to merit further study, and these were subjected to response calculations in order to determine their ability to perform the isolation function.

Figure 18 shows details of the nominal ring-gear design, while Figure 19 presents the analytical dynamic model used in the calculations. The dynamic analysis has been conducted for the dynamic force predicted to act at the lower planetary gear mesh frequency as a result of one planet-to-ring gear mesh. Figure 20 presents peak radial and axial dynamic force levels at indicated locations along the reference surface of the dynamic model. Figure 21 presents peak radial vibration amplitudes along the reference surface at the circumferential location of the dynamic force, while Figure 22 presents peak radial vibration amplitudes for several planes perpendicular to the ring-gear axis.

Figure 23 shows the design details of Modifications No. 1 and 2, with the corresponding analytical models shown in Figure 24. Figure 25 presents peak radial and axial dynamic force levels at indicated locations on the reference surface, for Modification No. 1, including the branch surface. Figure 26 shows peak radial vibration amplitudes along the reference surface at the circumferential location of the dynamic force, while Figure 27 presents peak radial vibration amplitudes for several planes perpendicular to the ring-gear axis for Modification No. 1.

With respect to Modification No. 2, Figure 28 presents peak force levels, while Figures 29 and 30 present, respectively, peak radial vibration amplitudes along the reference surfaces at the circumferential location of the dynamic force and peak radial vibration amplitudes for several planes perpendicular to the ring-gear axis for Modification No. 2.

Design details and the analytical model for Modification No. 3 are presented in Figures 31 and 32, respectively. Predicted peak forces, peak radial amplitudes at the dynamic force circumferential location, and peak radial amplitudes in several planes are shown in Figures 33, 34, and 35, respectively.

A summary of the peak dynamic forces at the upper and lower edges of the ring gear is presented in Tables XI and XII for the nominal and modified ring-gear configurations.

TABLE XI. CALCULATED PEAK RADIAL FORCE LEVELS AT INDICATED LOCATIONS ON CH-47 RING GEAR

| | Force Per Unit Circumferential Length (lb/in.) | | | |
|---|---|---|---|---|
| Location | Nominal Model | Modification 1 | Modification 2 | Modification 3 |
| Upper Edge | 0.1 | 8.6 | 8.8 | 6.4 |
| Lower Edge | 9.1 | 0 | 0 | 0.8 |

TABLE XII. CALCULATED PEAK AXIAL FORCE LEVELS AT INDICATED LOCATIONS ON CH-47 RING GEAR

| | Force Per Unit Circumferential Length (lb/in.) | | | |
|---|---|---|---|---|
| Location | Nominal Model | Modification 1 | Modification 2 | Modification 3 |
| Upper Edge | 0.9 | 13.4 | 14.1 | 18.7 |
| Lower Edge | 2.6 | 1.5 | 1.6 | 2.5 |

## IDENTIFICATION OF COMPONENT MODIFICATIONS WHICH WOULD RESULT IN SIGNIFICANT NOISE REDUCTION

With respect to the input spiral bevel shaft, examination of the results shown in Figures 3 through 8 indicates clearly that Modification No. 5 exhibits the best vibration reduction results of all shaft-configuration modifications considered. Addition of higher radial stiffness thrust bearings further improves this result, as shown in Figure 9. Consequently, the shaft configuration shown in Figure 7 is recommended for test evaluation. This redesigned component is shown in Figure 36. In addition, it is recommended that tests of this configuration be conducted with increased thrust bearing radial stiffness, which the mounting cartridge shown in Figure 37 has been designed to provide through the use of radially-adjustable locking screws. A subassembly of these items appears in Figure 38.

With respect to the lower-stage planetary sun gear shaft, examination of Figures 11 through 17 shows clearly that Modification No. 7 exhibits the best vibration reduction results of all the modifications considered. Consequently, this modification is recommended for test evaluation. It is conceded that Modification No. 7 involves a heavier shaft than that in the nominal design. The recommendation is made nevertheless, since the primary objective of this program is continued verification of low vibration and noise design methods, rather than final design of flight-quality hardware. Such a design would be a logical sequel to this program, utilizing the proven procedures. The redesigned shaft is shown in Figure 39.

With respect to the ring gear, examination of Tables XI and XII, which contain data extracted from Figures 20, 25, 28, and 32, indicates that all modifications yield considerably reduced radial dynamic force levels at the casing lower edge with some changes in axial dynamic force levels at that location. The modifications, in effect, all transfer the lower planetary dynamic tooth forces to the upper ring-gear edge, where it is reacted by the transmission cover.

Examination of Figures 21, 26, 29, and 34, which show peak amplitudes along the ring gear at the circumferential location of the dynamic force, indicate clearly the higher amplitudes associated with the increased isolation and flexibility of the lower-stage planetary ring gear. They are of the order of 0.1 to 0.2 mil in all cases. Figures 22, 27, 30, and 35 confirm these results. It should be noted that fatigue life may become the limiting factor for the cantilevered ring-gear configurations. Detailed and complete stress analyses have not been conducted for the modifications shown in Figures 23 and 31. Such calculations are recommended prior to final design of parts for test evaluation.

As a result of the foregoing study, it is recommended that ring-gear Modification No. 3 be selected for first evaluation on the basis that its fabrication cost will be reasonably low. This modification is shown in Figure 40.

It is recommended that either Modification No. 1 or No. 2 be selected for testing subsequent to Modification No. 3, on the basis that while their

isolation properties are slightly better than those of No. 3, their fabrication costs will be higher. Designs for Modifications No. 1 and No. 2 are shown in Figures 41 and 42.

## CONCLUSIONS

The following conclusions are drawn as a result of the studies reported herein:

1. Practical, low-cost, shaft-bearing system modifications have been identified for the bevel-carrying gearbox shafts. These modifications are predicted to yield dynamic force reductions of 8 db and 11 db (re. 1.0 lb) in the shaft bearings at the lower-stage planetary and bevel gear mesh frequencies, respectively.

2. Since it was not considered feasible to alter spiral-bevel shaft bearing locations and diameters, mass distribution modifications were considered. The proposed modifications would increase the weight of the bevel gear shaft from 38 to 55 lbs and the weight of the lower-stage planetary sun gear shaft from 46 to 79 lbs. The noise produced by the gearbox casing as a result of the bearing dynamic forces should be reduced in proportion to the force reductions noted in Conclusion 1.

3. Practical ring-gear modifications have been identified. These modifications are predicted to provide effective isolation of the lower portions of the gearbox from tooth dynamic forces originating in the lower-stage planetary meshes. Since the nominal ring gear design is known to provide an effective path for lower-stage planetary and bevel gear mesh frequency vibrations to reach the gearbox casing [10], modifications to the spiral bevel gear shafts alone may not be fully effective. Instead, ring-gear isolation must be combined with such modifications for effective noise reduction at these frequencies.

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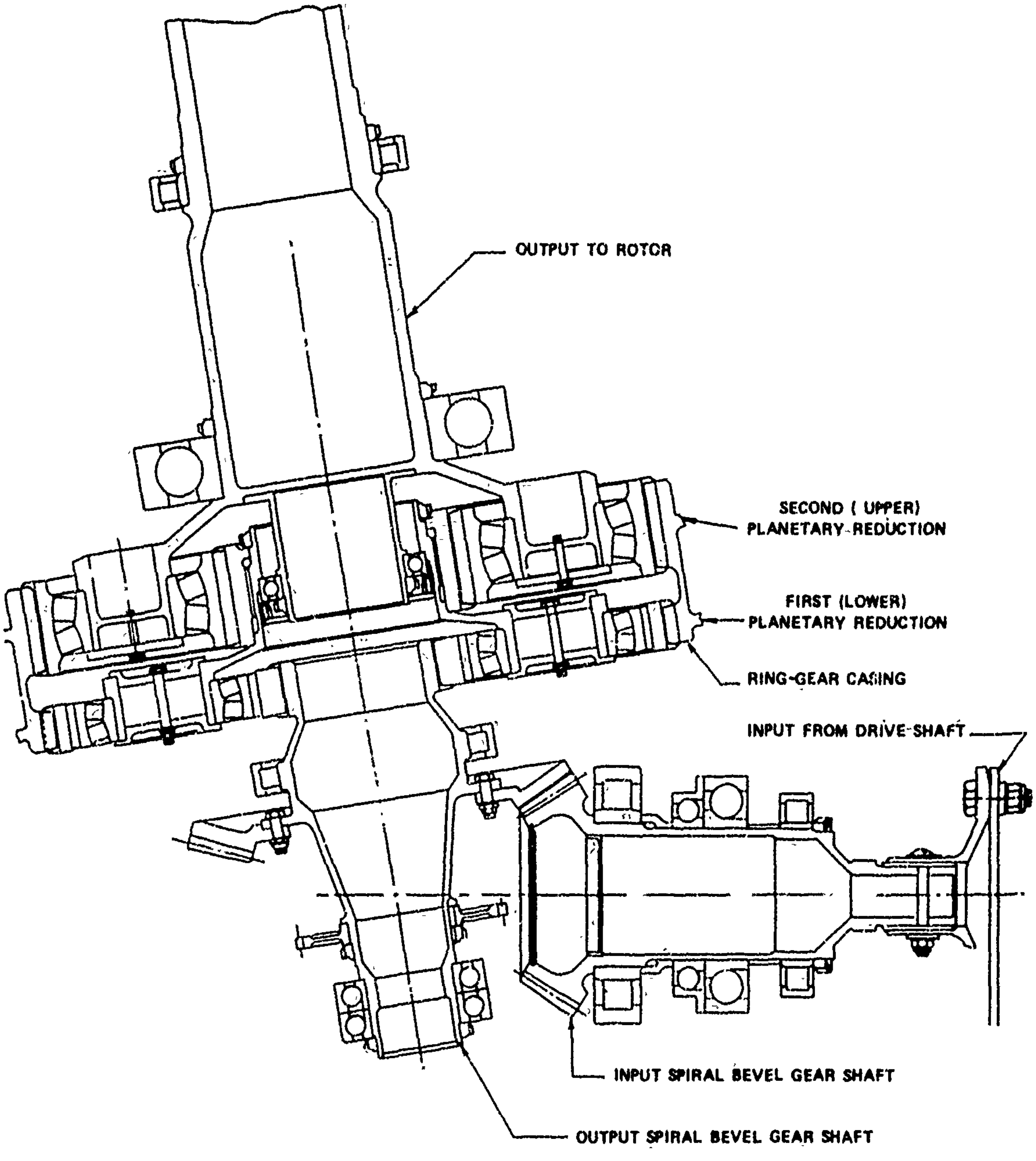



Figure 1. CH-47 Forward Rotor-Drive Gearbox Bevel Gear Shaft-Bearing System.

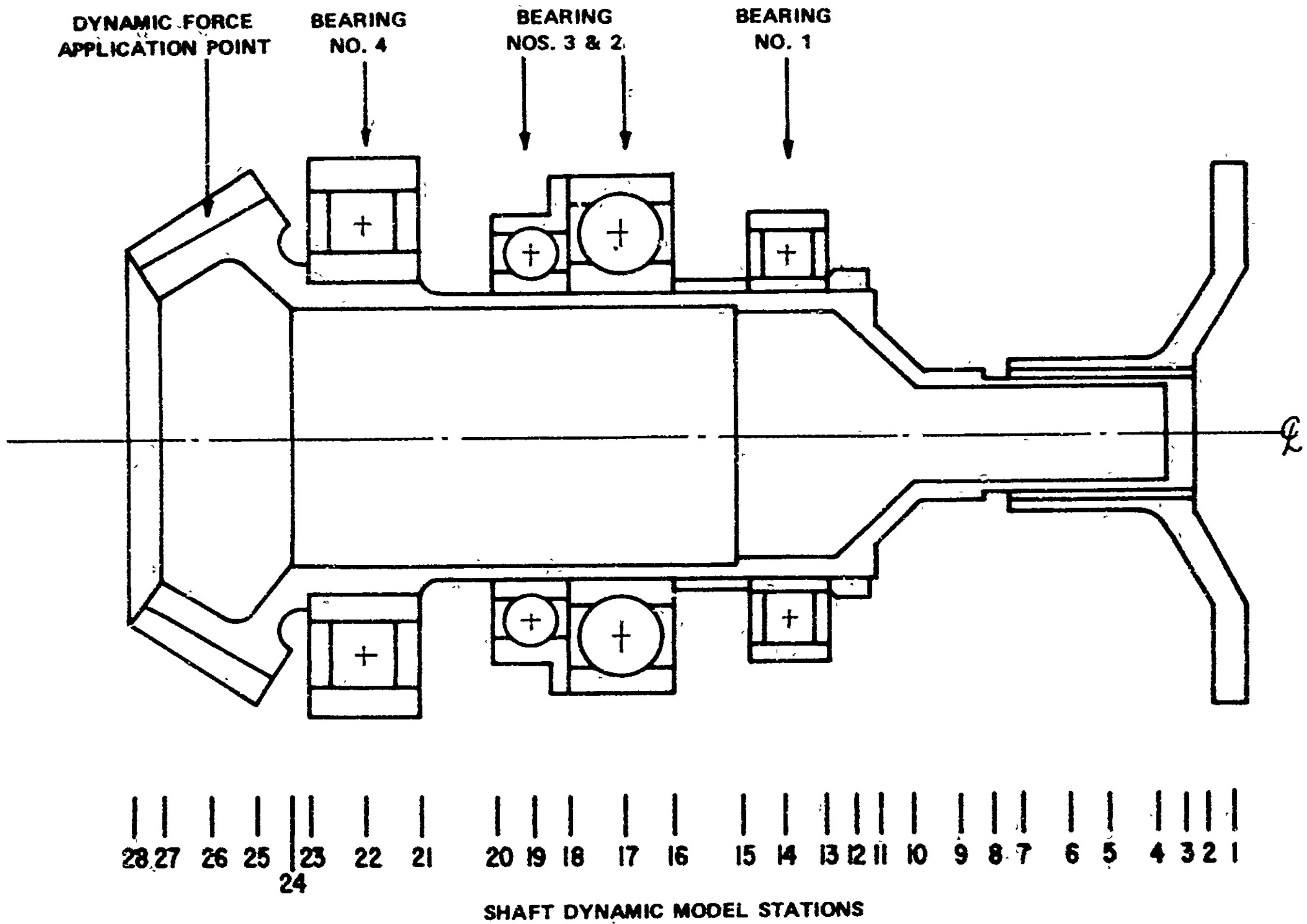



Figure 2. CH-47 Input Bevel Gear Shaft Dynamic Modeling Details.

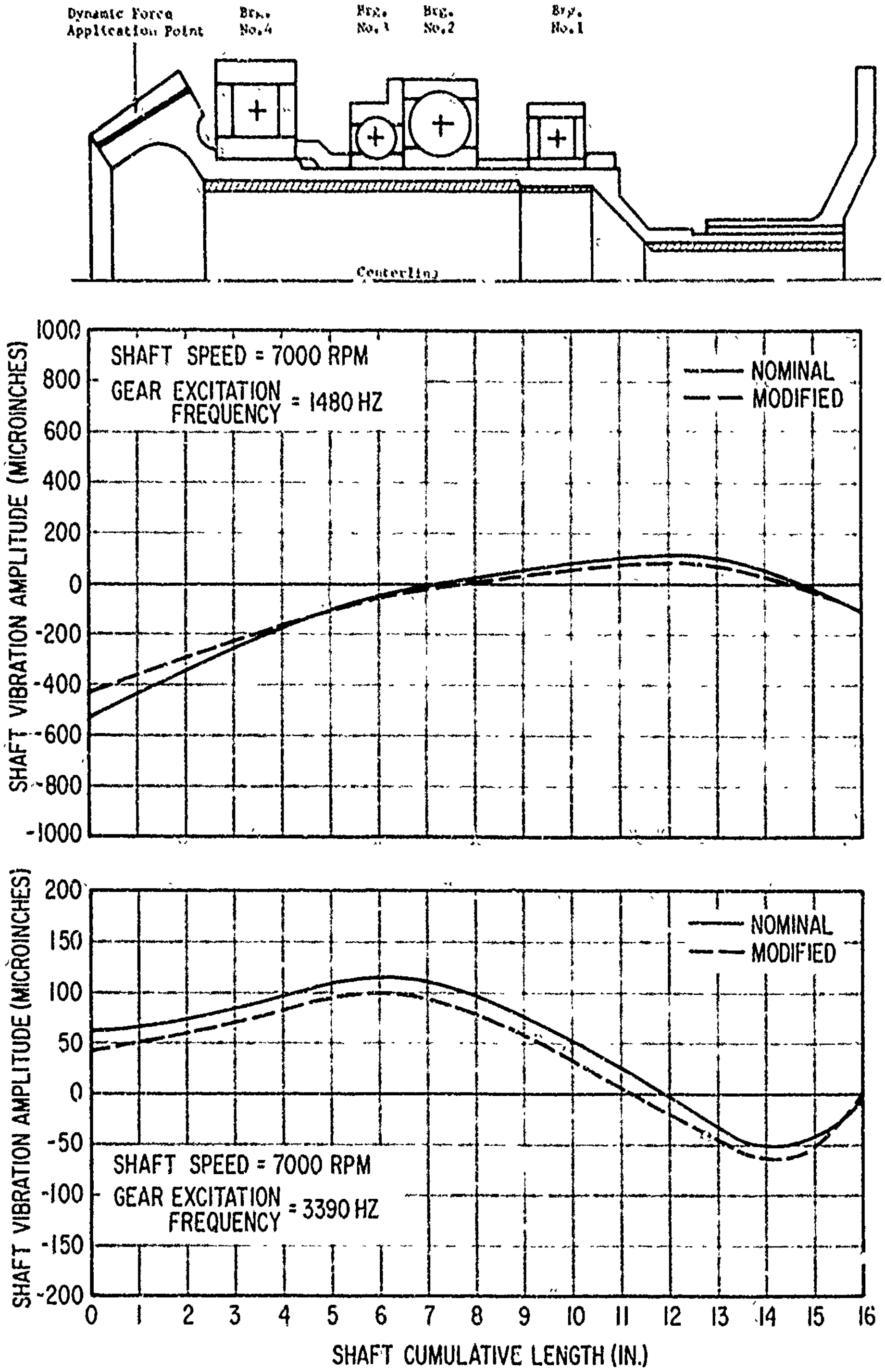



Figure 3. Calculated Vibration Amplitudes for CH-47 Input Bevel Gear Shaft, Nominal and Modified Configurations No. 1.

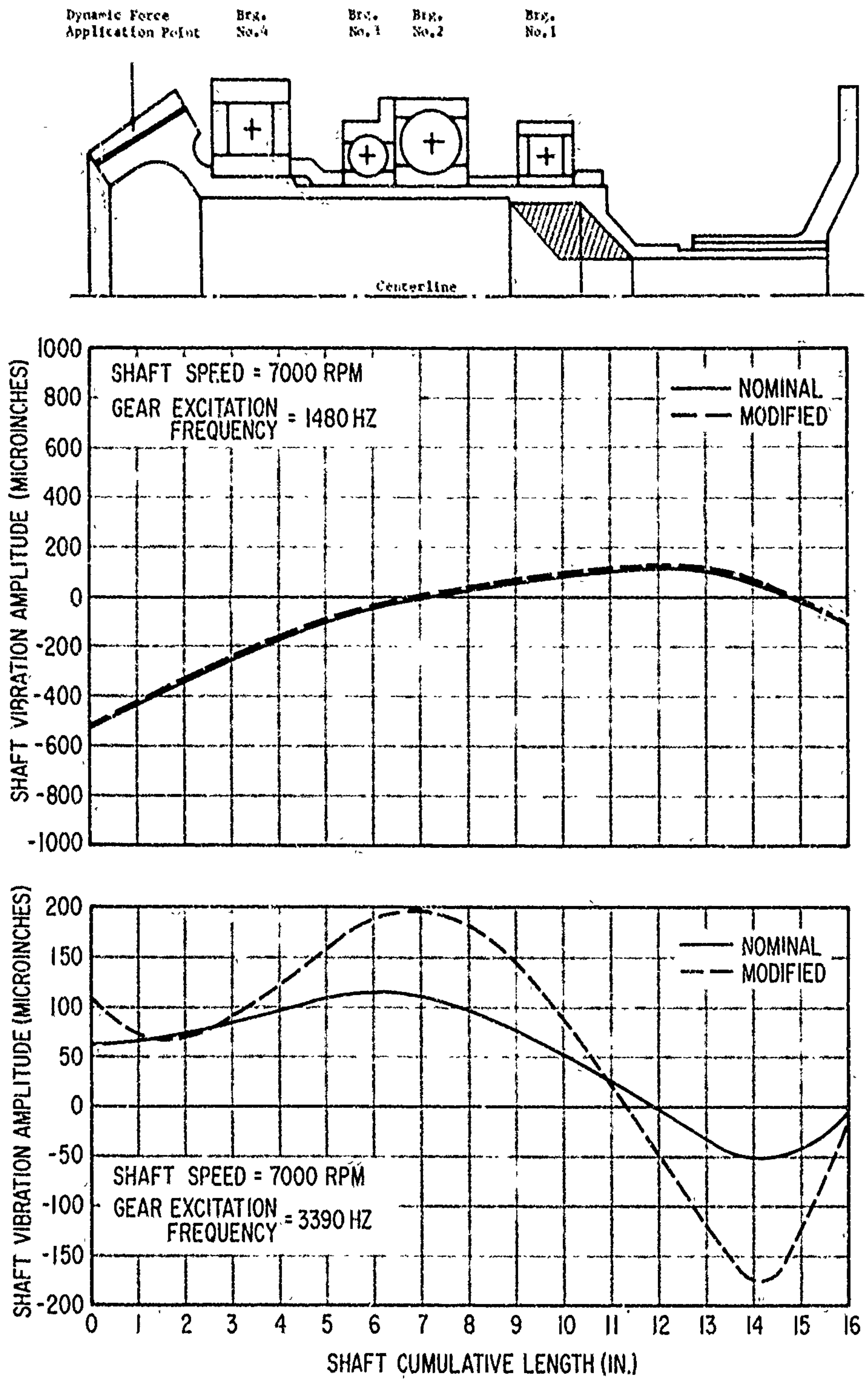



Figure 4. Calculated Vibration Amplitudes for CH-47 Input Bevel Gear Shaft, Nominal and Modified Configurations No. 2.

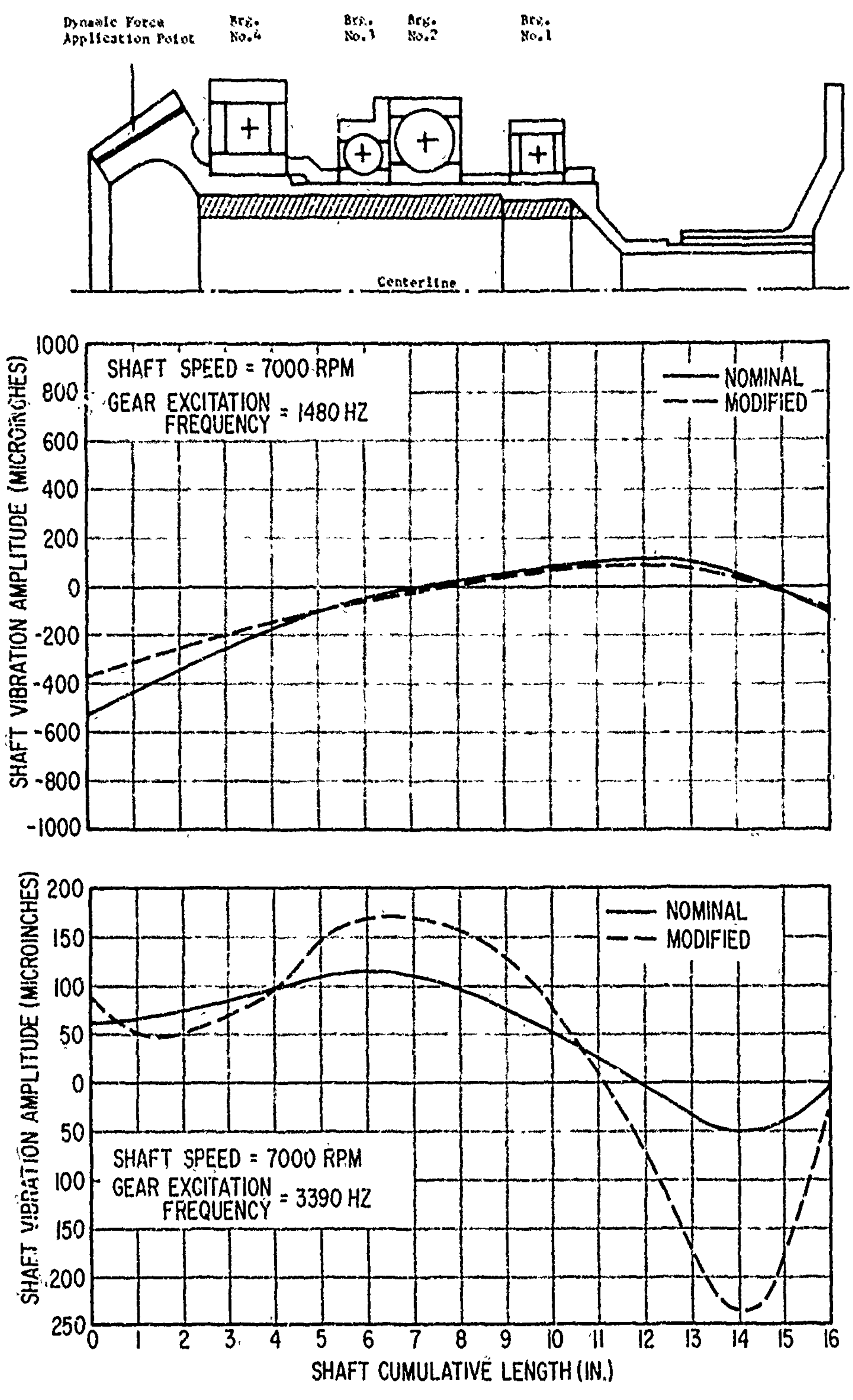



Figure 5. Calculated Vibration Amplitudes for CH-47 Input Bevel Gear Shaft, Nominal and Modified Configurations No. 3.

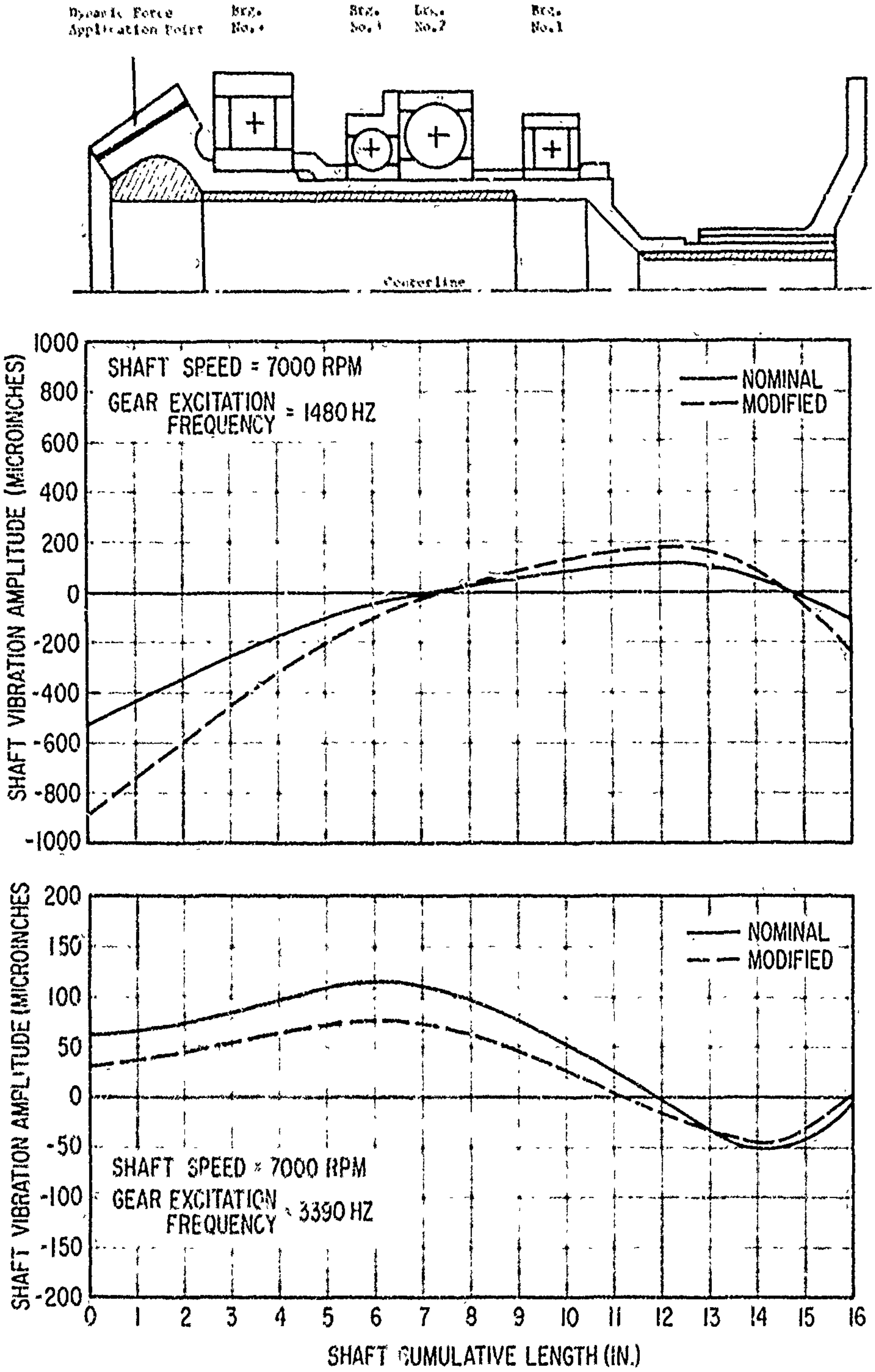



Figure 6. Calculated Vibration Amplitudes for CH-47 Input Bevel Gear Shaft, Nominal and Modified Configura ons No. 4.

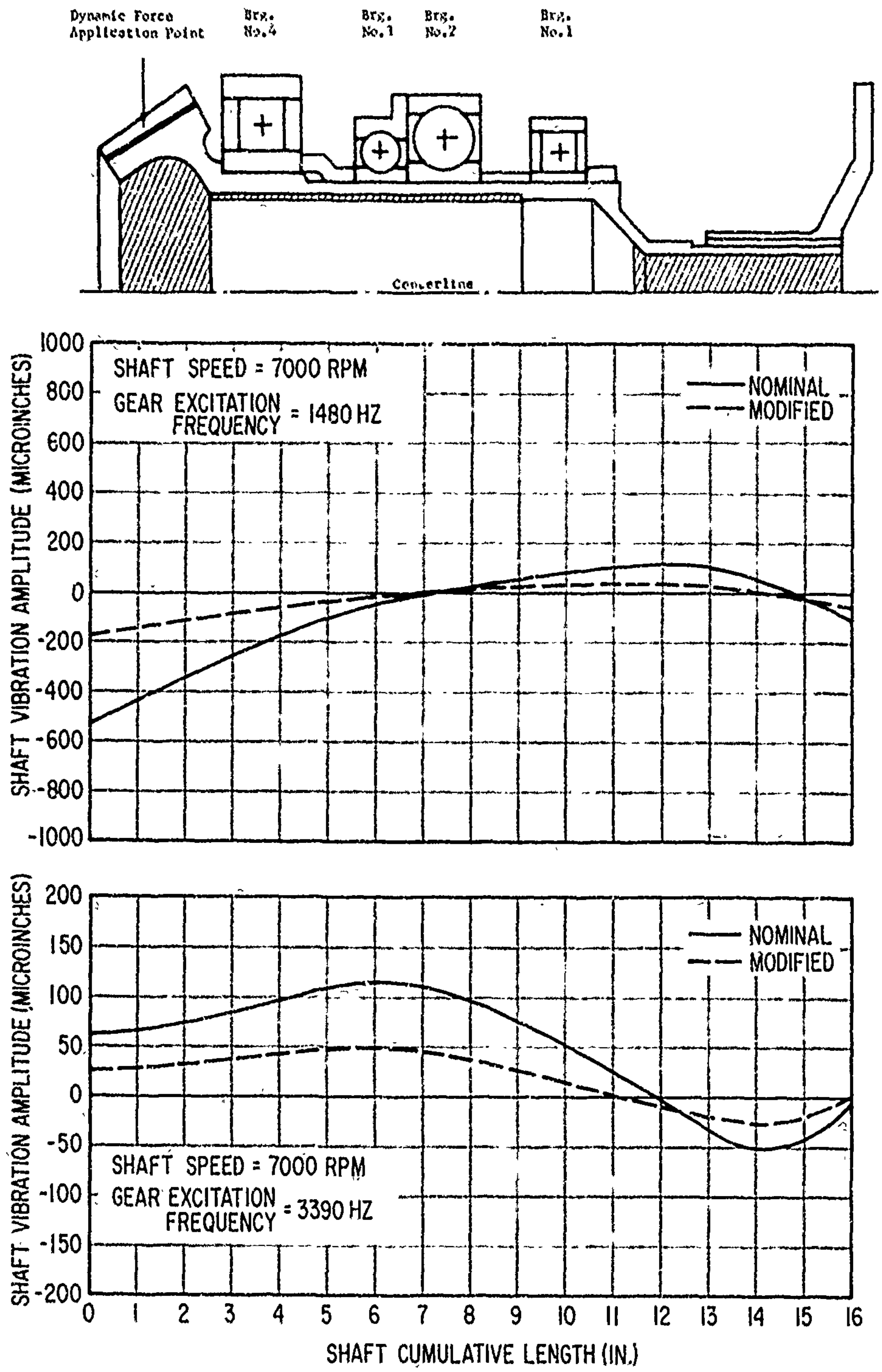



Figure 7. Calculated Vibration Amplitudes for CH-47 Input Bevel Gear Shaft, Nominal and Modified Configurations No. 5.

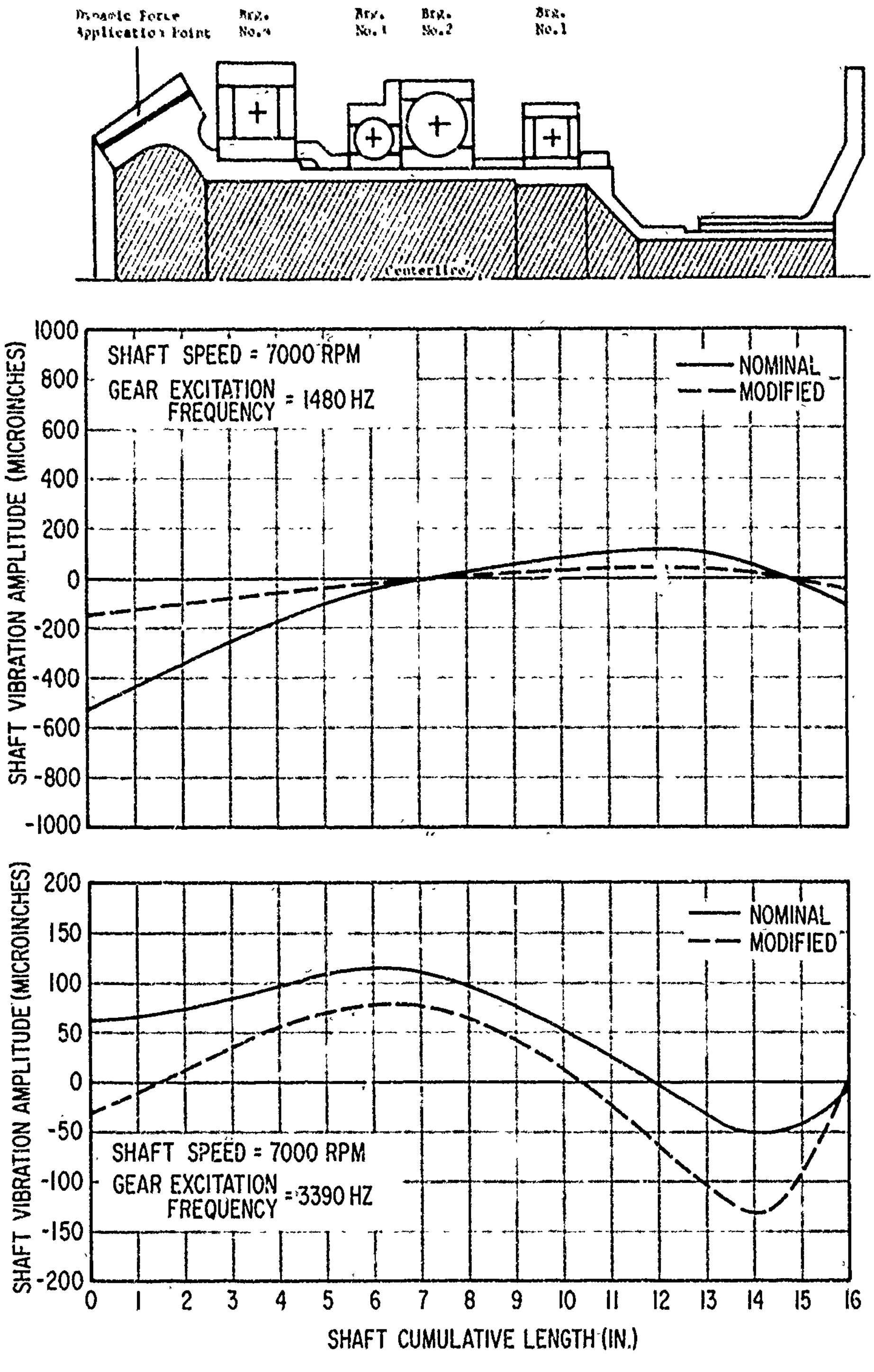



Figure 8. Calculated Vibration Amplitudes for CH-47 Input Bevel Gear Shaft, Nominal and Modified Configurations No. 6.

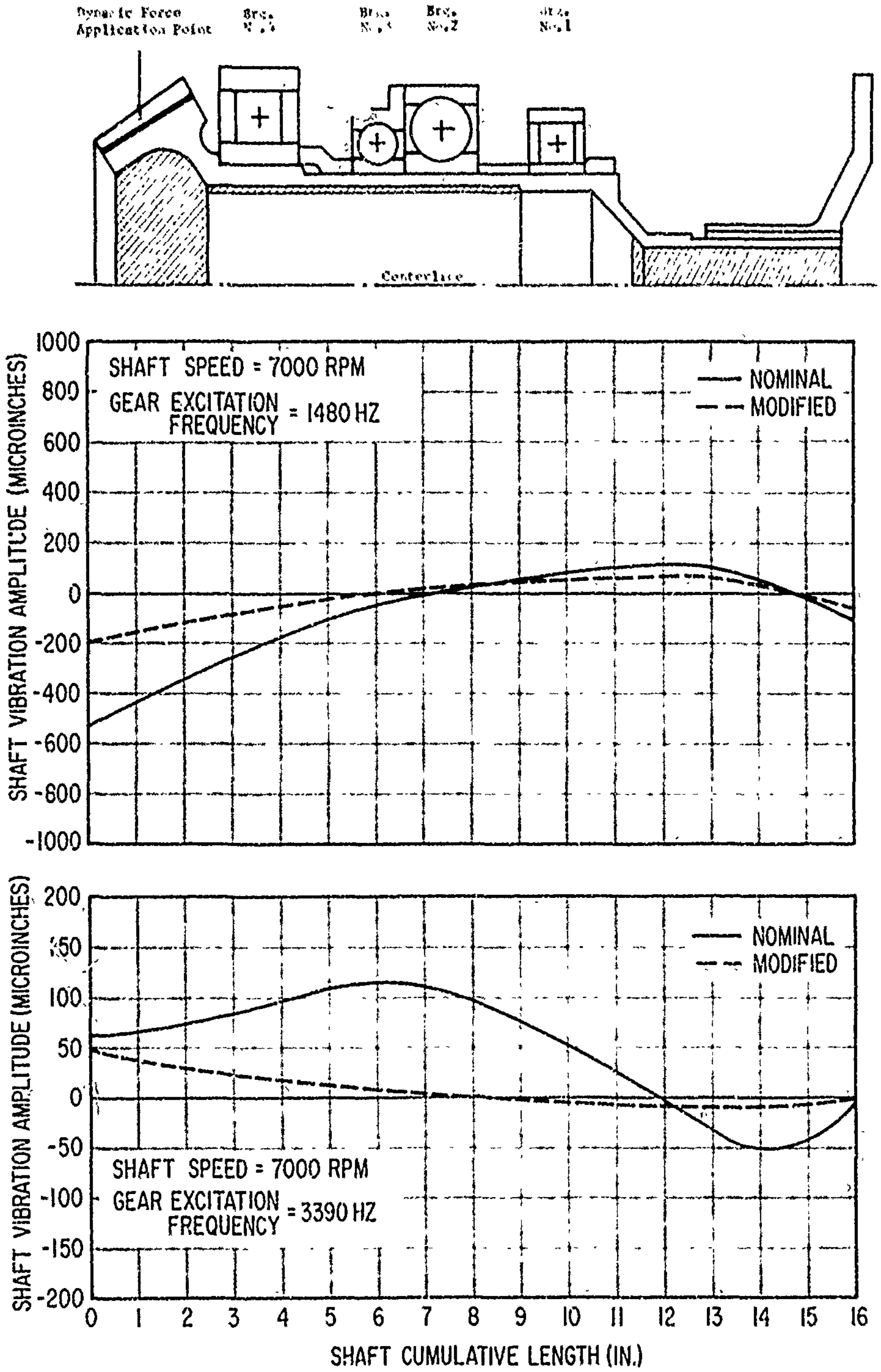



Figure 9. Calculated Vibration Amplitudes for CH-47 Input Bevel Gear Shaft, Nominal and Modified Configurations No. 7.

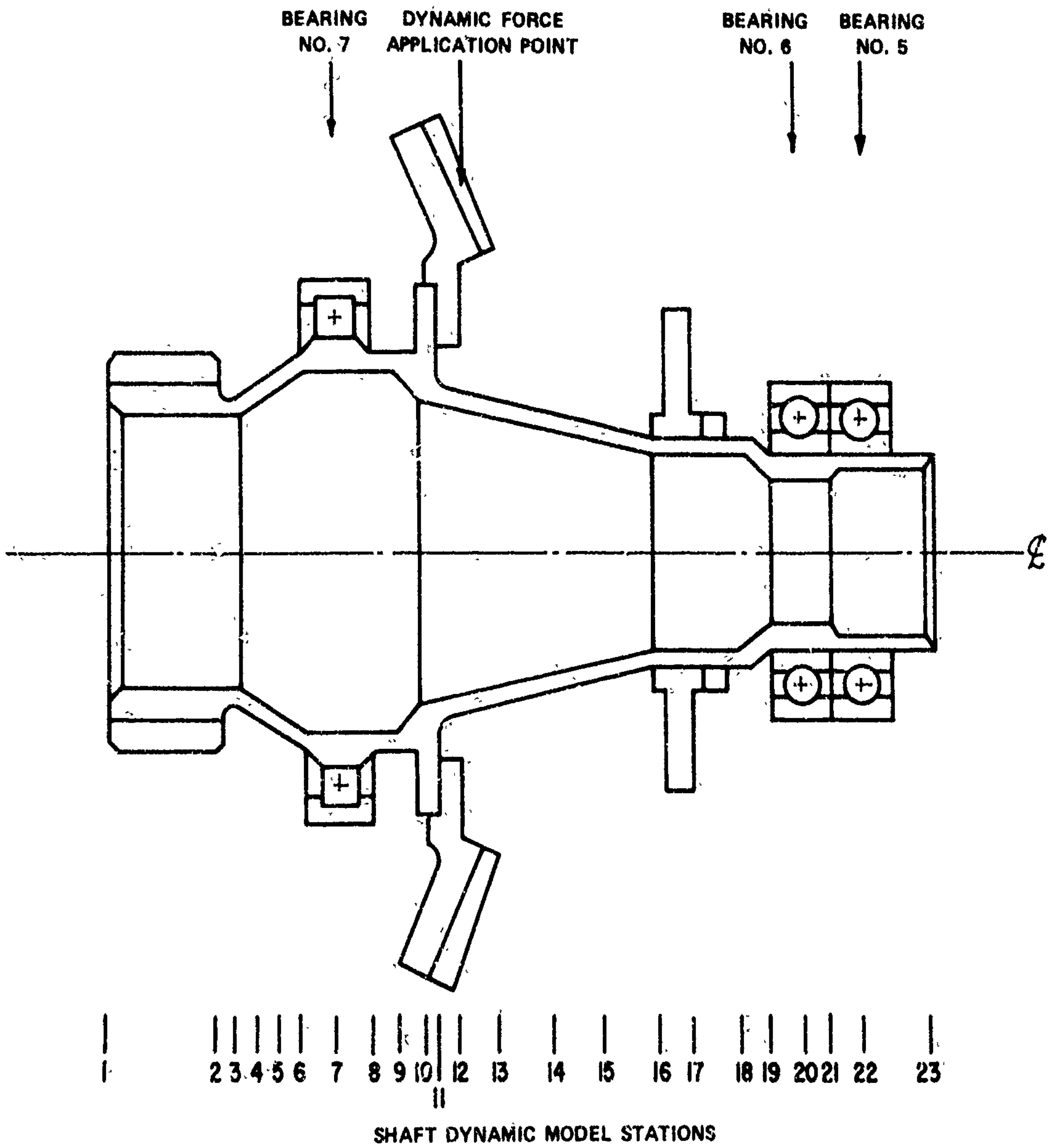



Figure 10. CH-47 Lower Stage Planetary Sun Gear Shaft Dynamic Modeling Details.

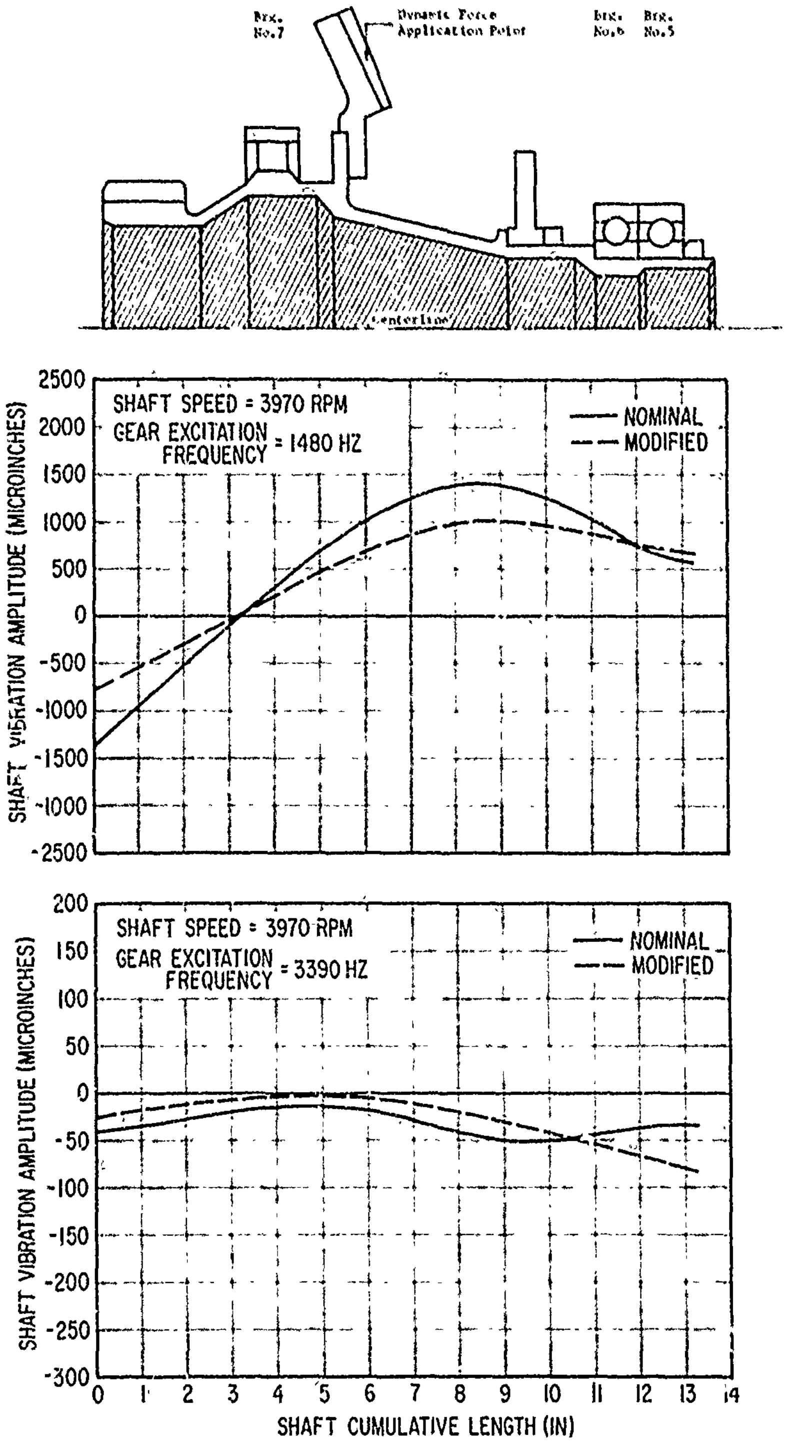



Figure 11. Calculated Vibration Amplitudes for CH-47 Lower-Stage Planetary Sun Gear Shaft, Nominal and Modified Configurations No. 1.

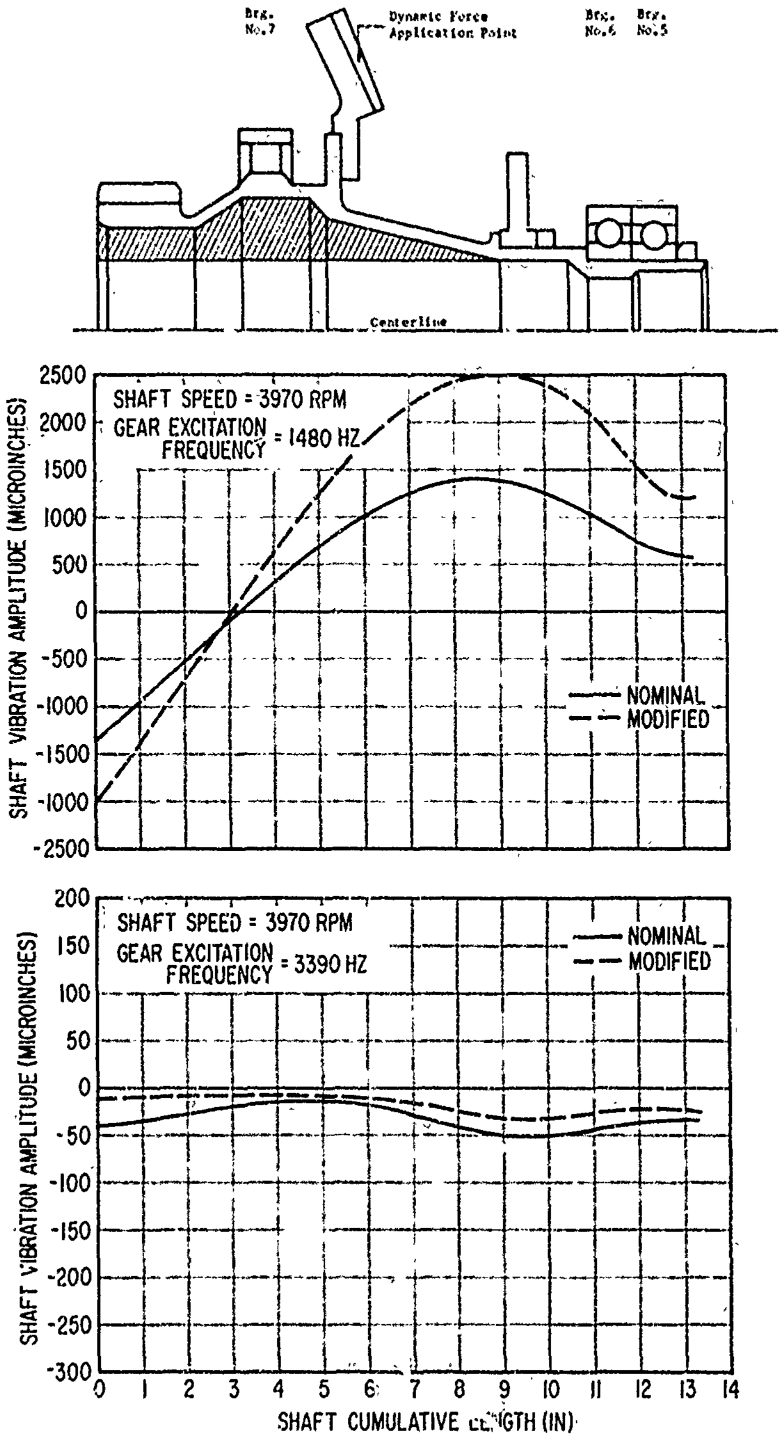



Figure 12. Calculated Vibration Amplitudes for CH-47 Lower-Stage Planetary Sun Gear Shaft, Nominal and Modified Configurations No. 2.

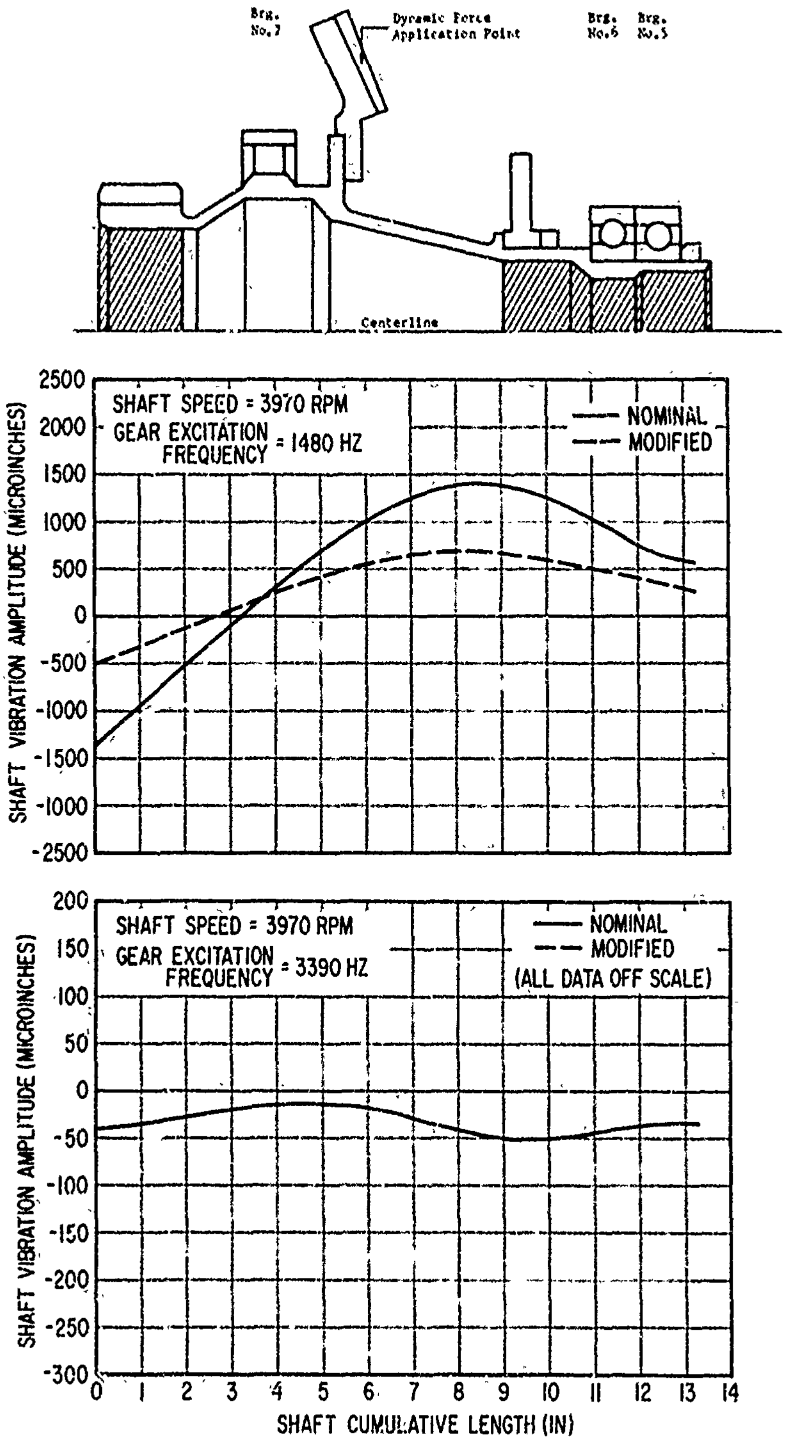



Figure 13. Calculated Vibration Amplitudes for CH-47 Lower-Stage Planetary Sun Gear Shaft, Nominal and Modified Configurations No. 3.

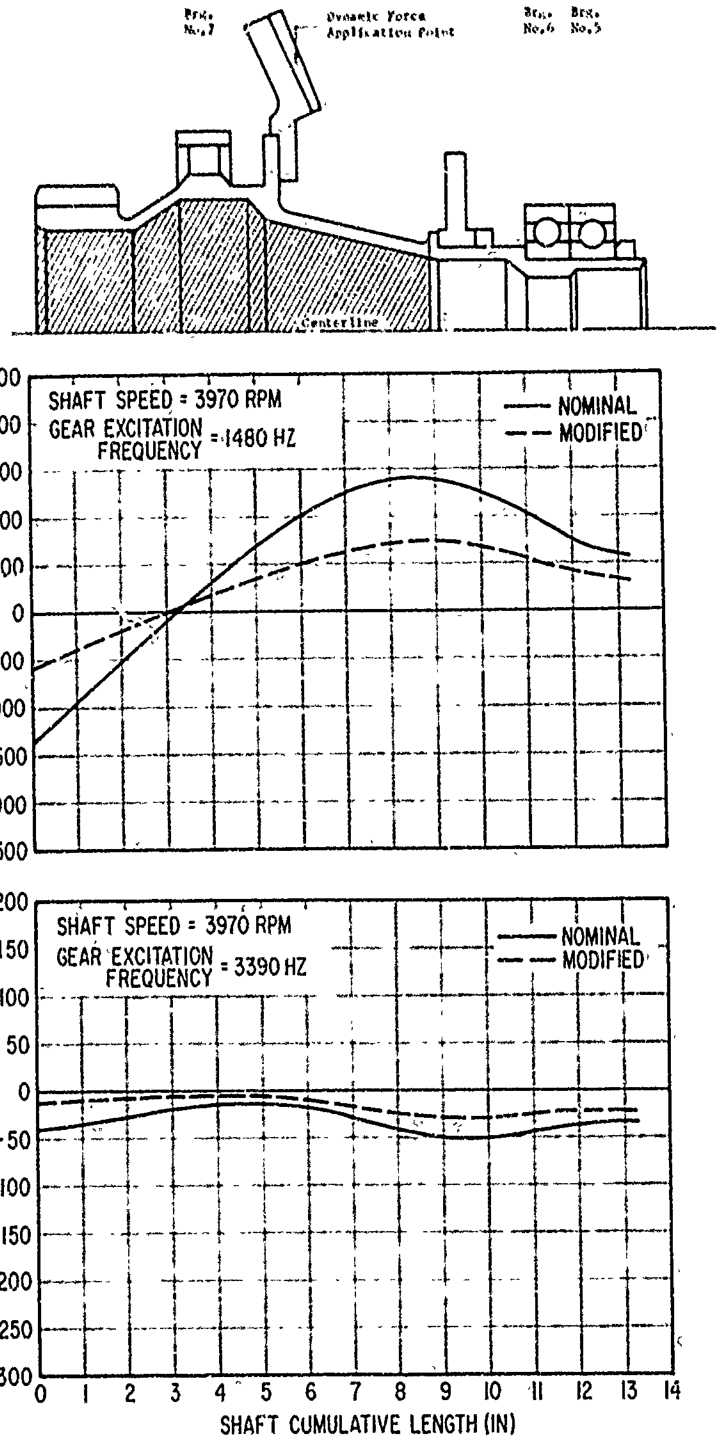



Figure 14. Calculated Vibration Amplitudes for CH-47 Lower-Stage Planetary Sun Gear Shaft, Nominal and Modified Configurations No. 4.

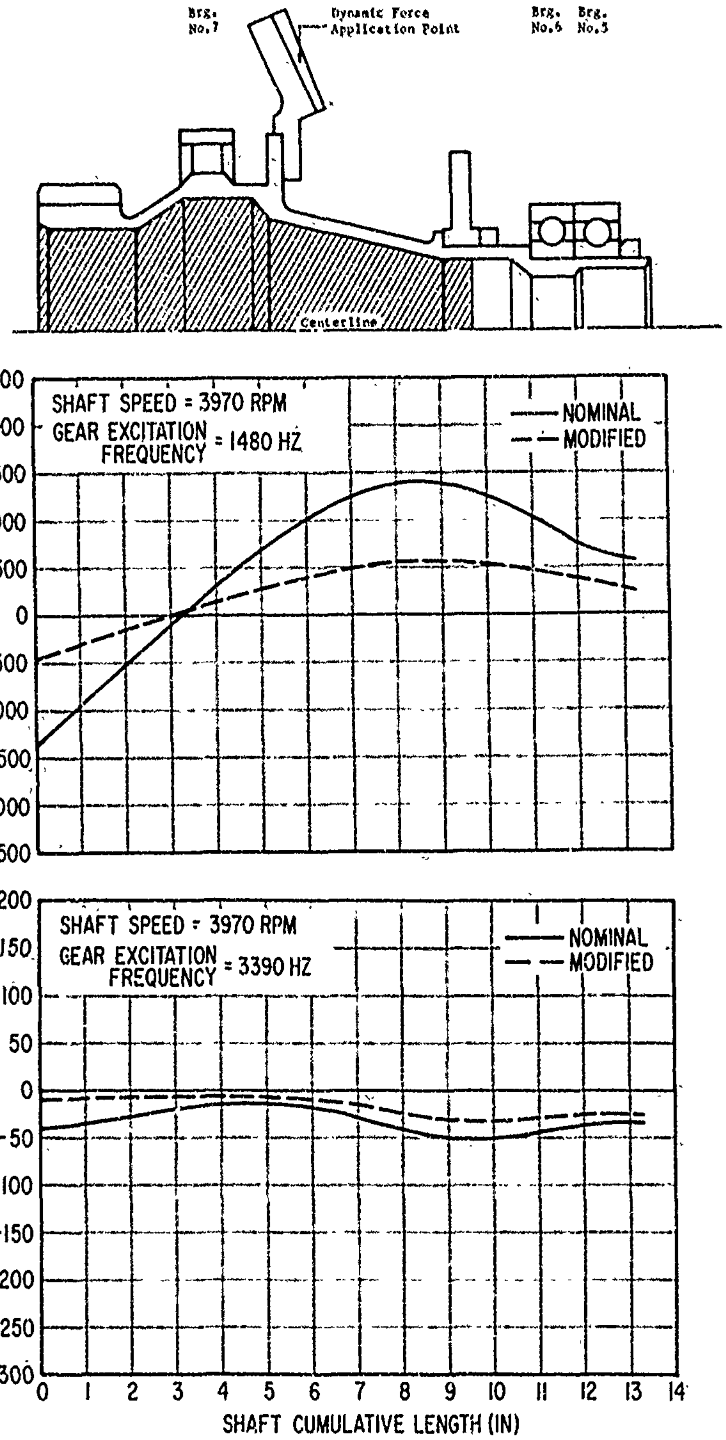



Figure 15. Calculated Vibration Amplitudes for CH-47 Lower-Stage Planetary Sun Gear Shaft, Nominal and Modified Configurations No. 5.

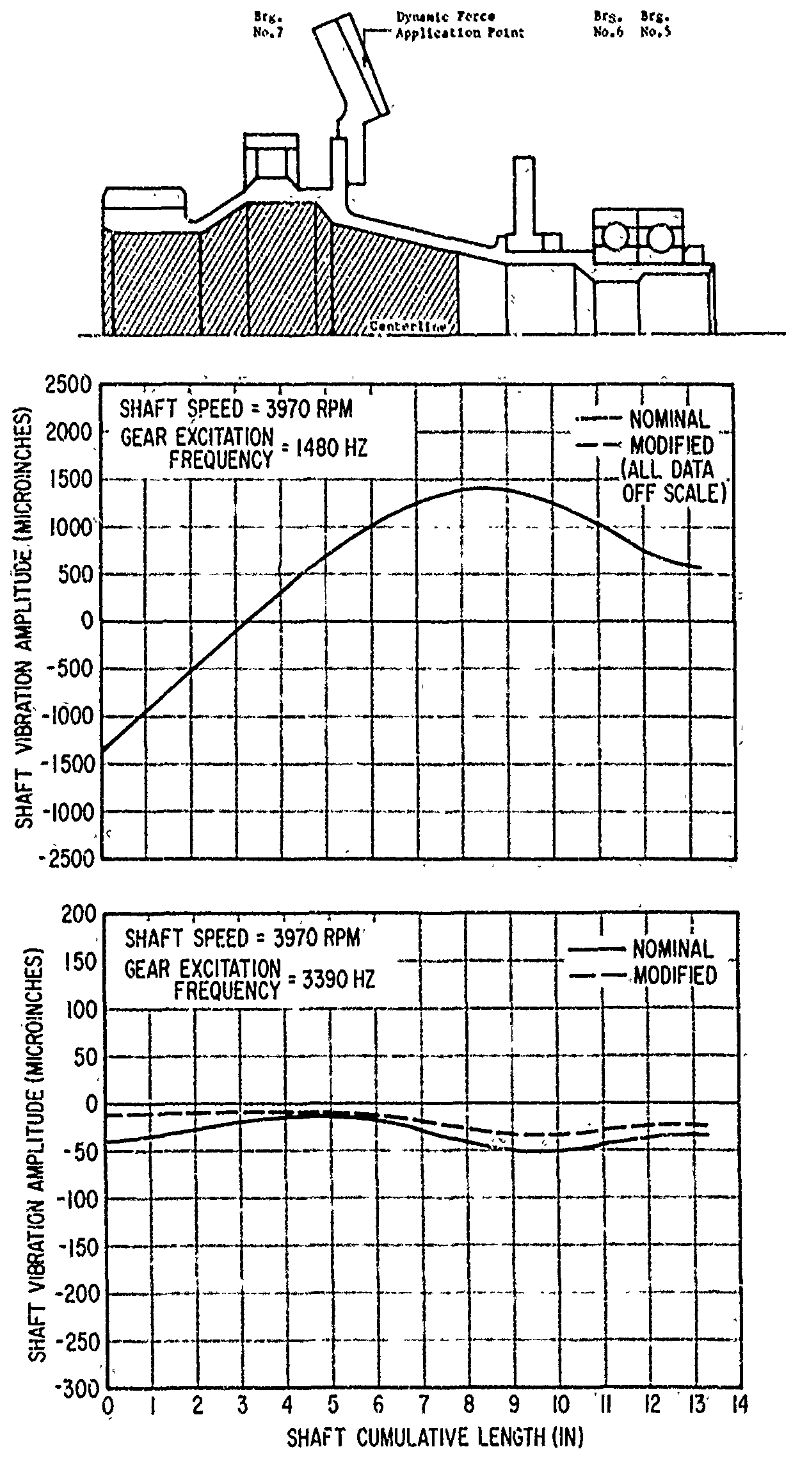



Figure 16. Calculated Vibration Amplitudes for CH-47 Lower-Stage Planetary Sun Gear Shaft, Nominal and Modified Configurations No. 6.

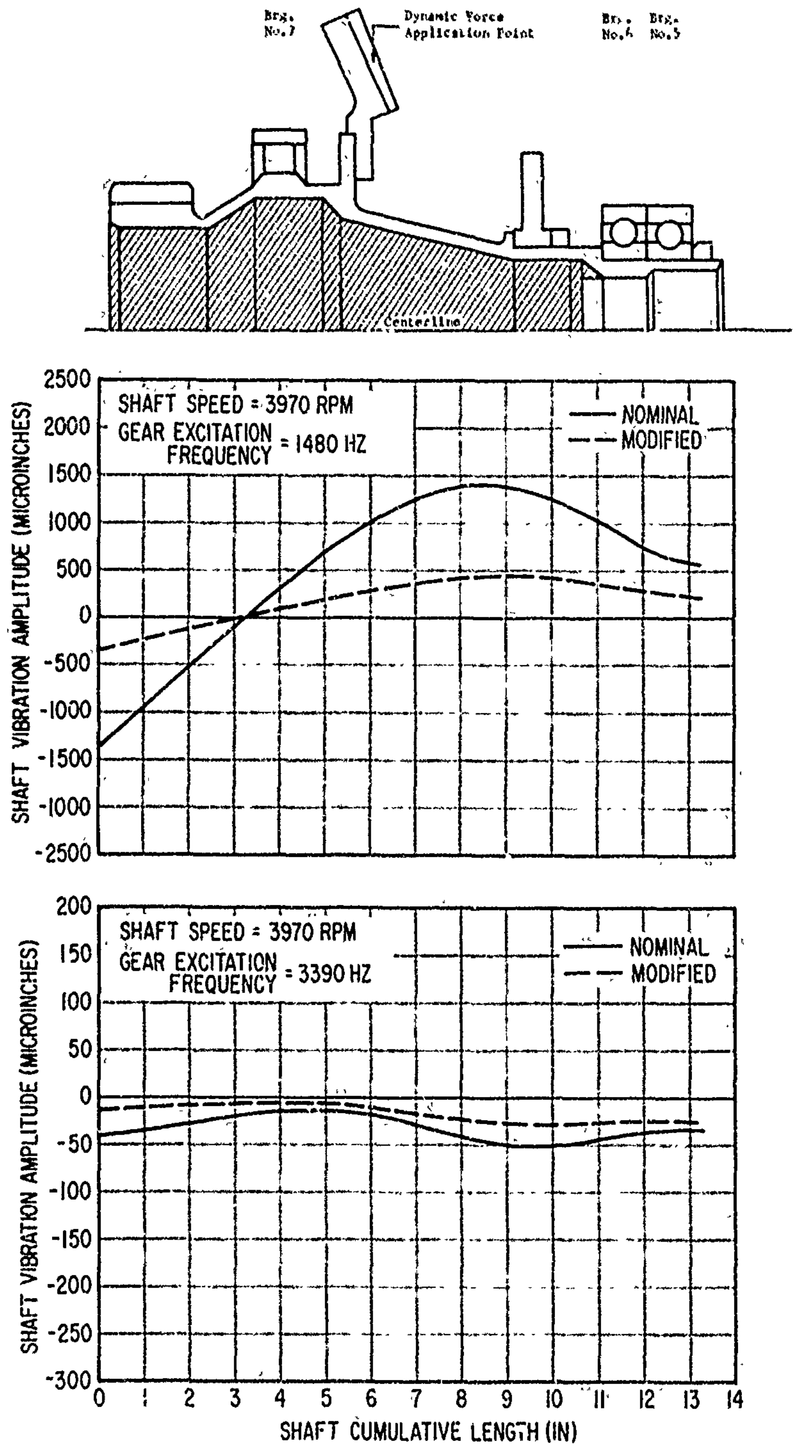



Figure 17. Calculated Vibration Amplitudes for CH-47 Lower-Stage Planetary Sun Gear Shaft, Nominal and Modified Configurations No. 7.

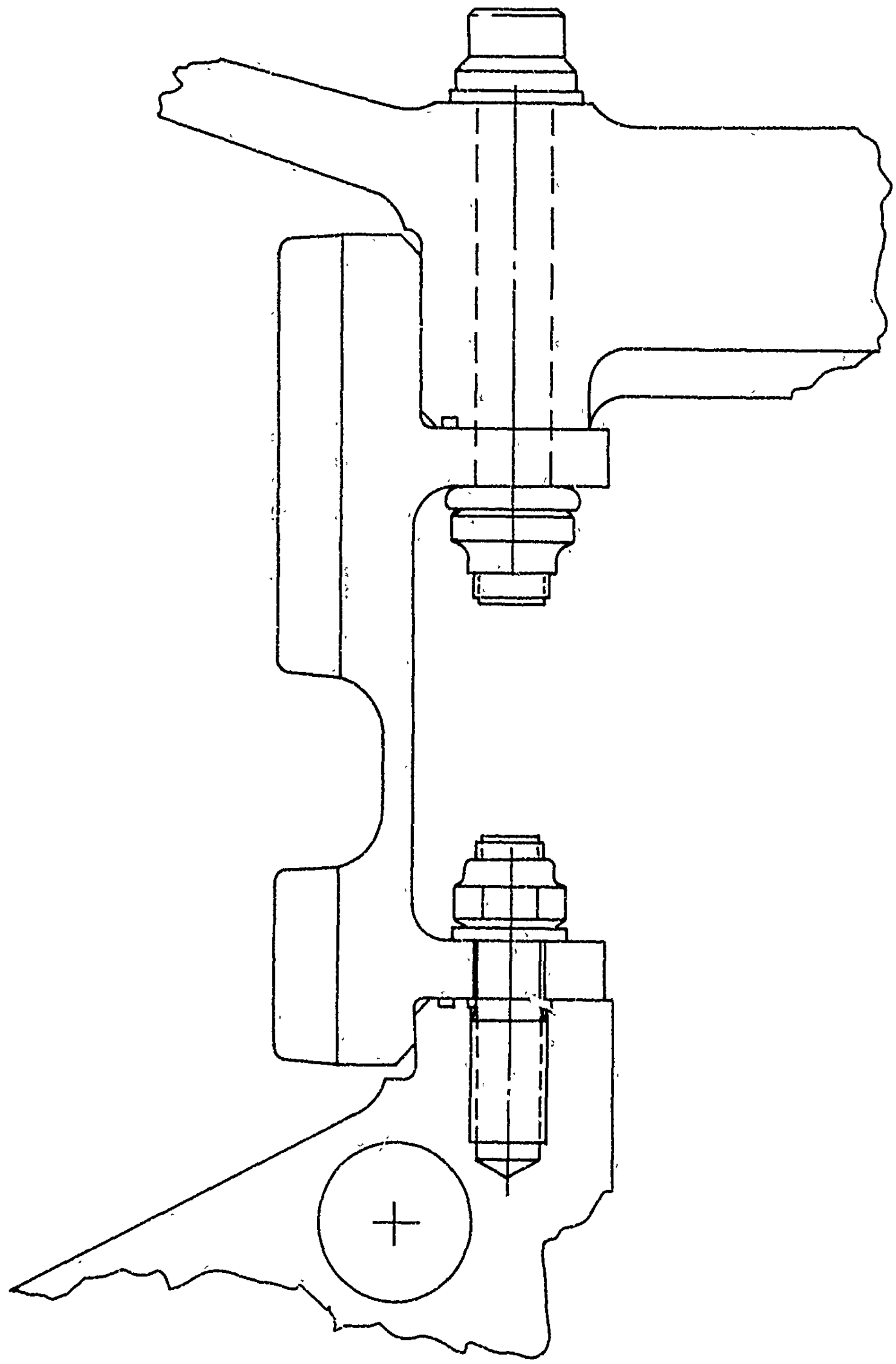


Figure 18. Nominal Ring-Gear Design.

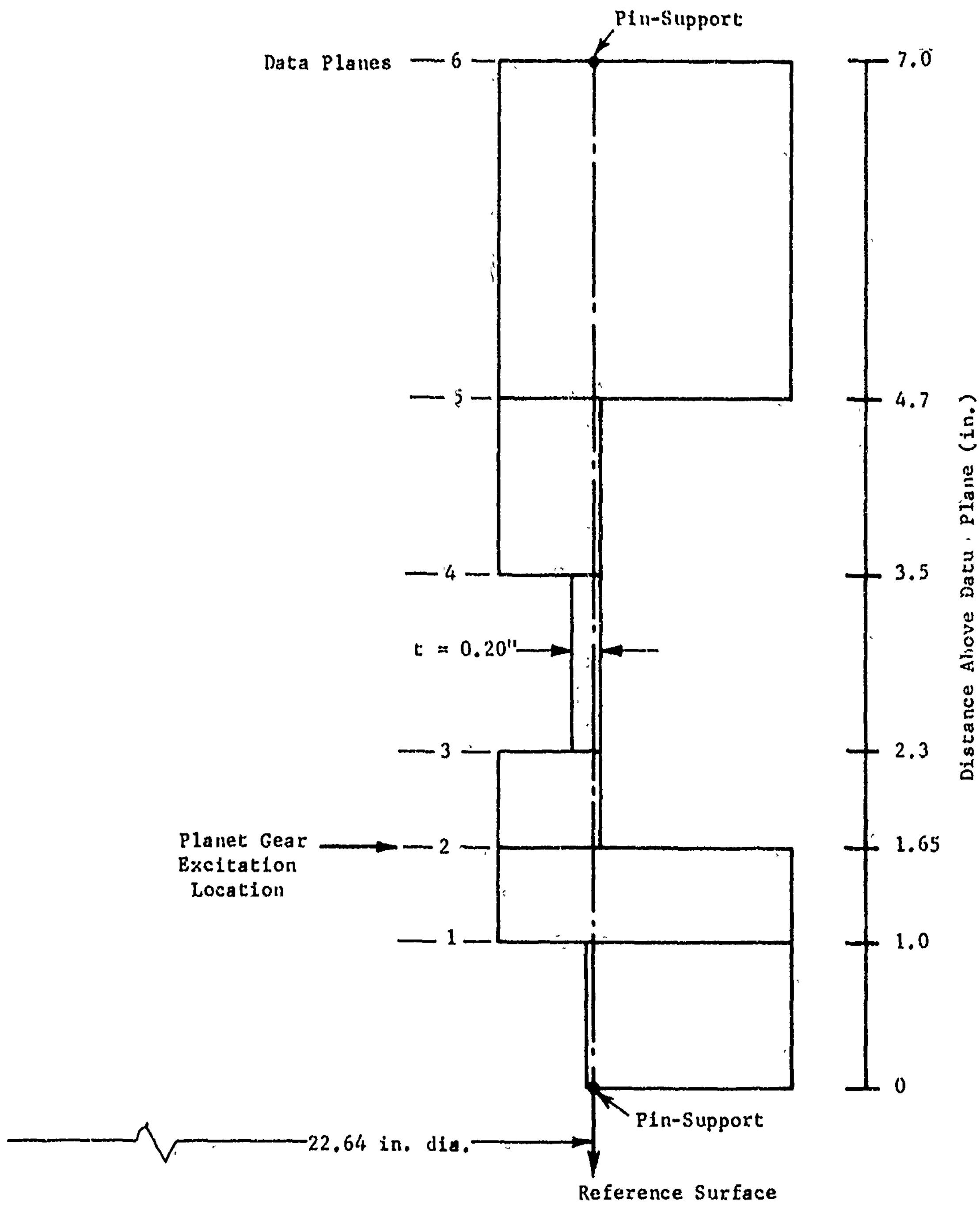



Figure 19. Analytical Dynamic Model for Nominal Ring-Gear Design.

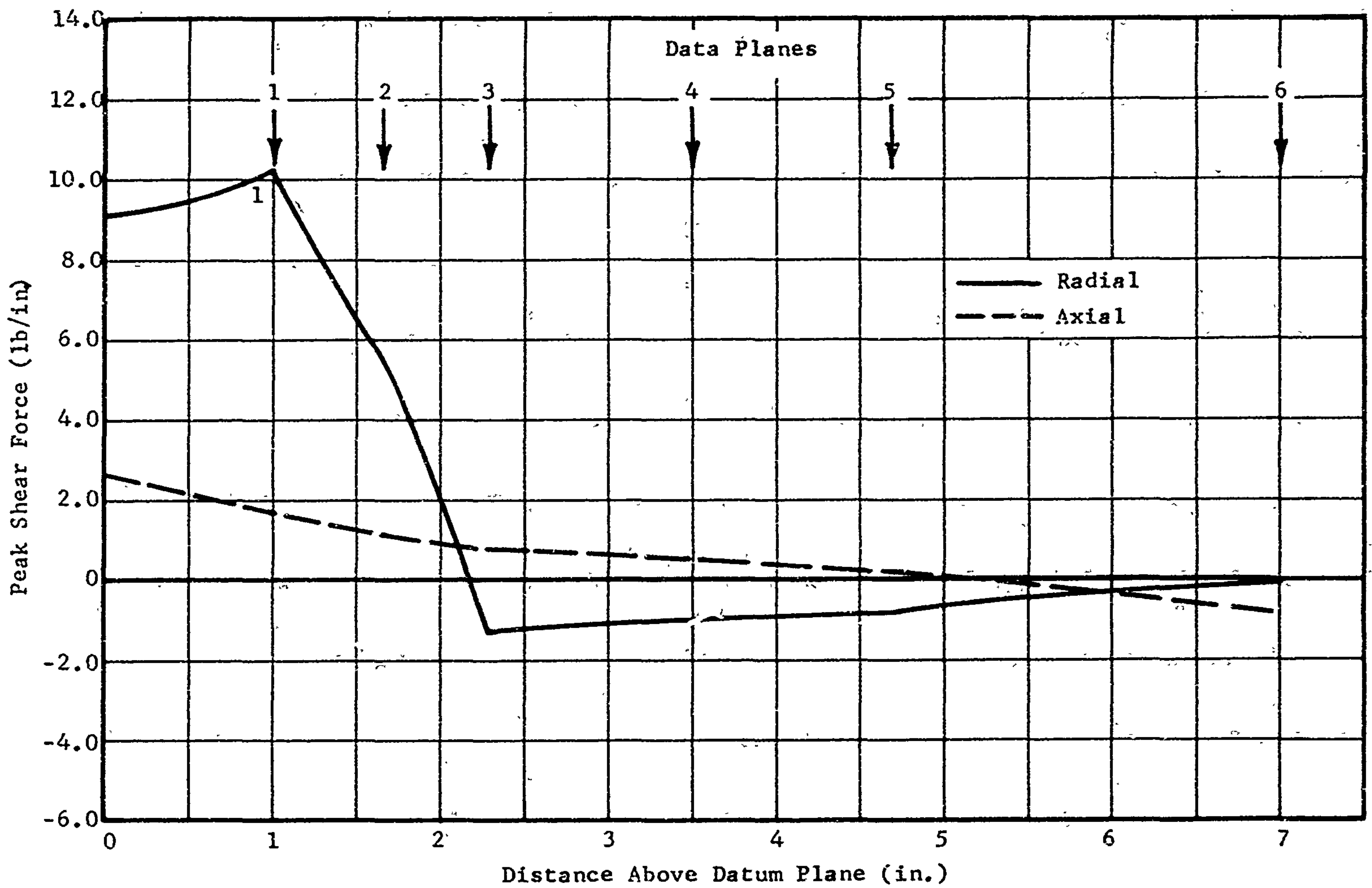



Figure 20. Peak Radial and Axial Dynamic Force Levels for Analytical Dynamic Model.

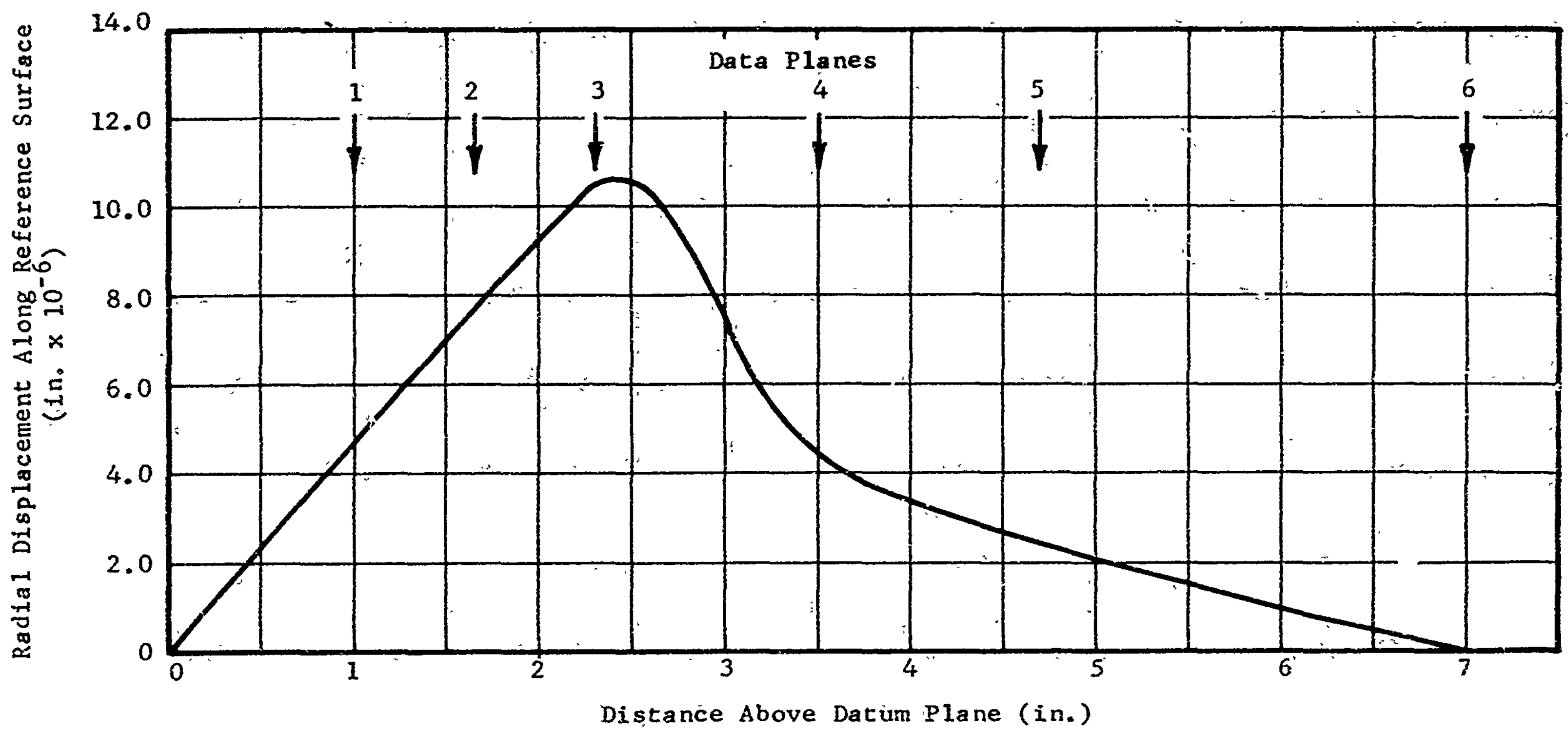



Figure 21. Peak Radial Vibration Amplitudes Along the Reference Surface at the Circumferential Location of the Dynamic Force for Nominal Model.

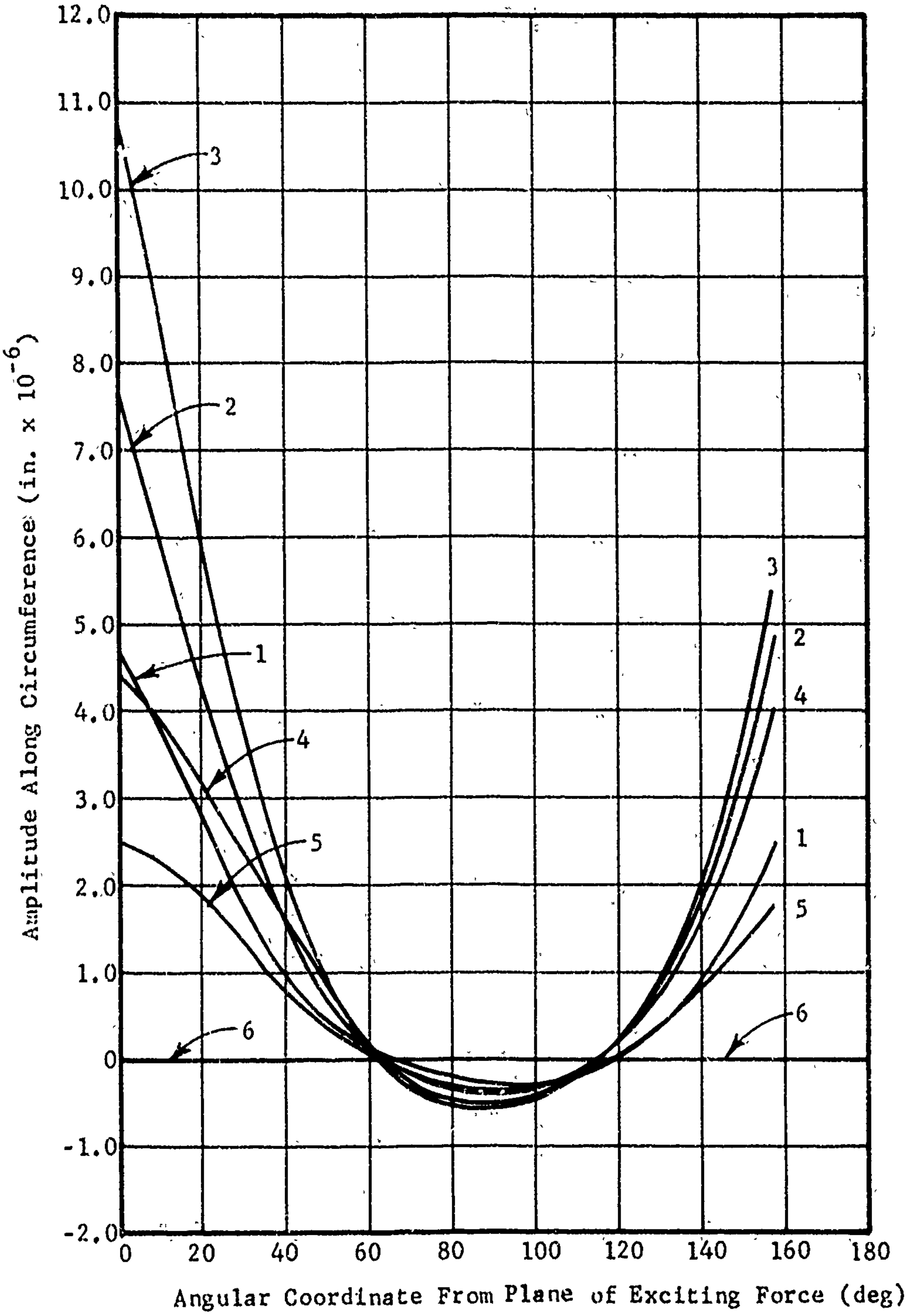
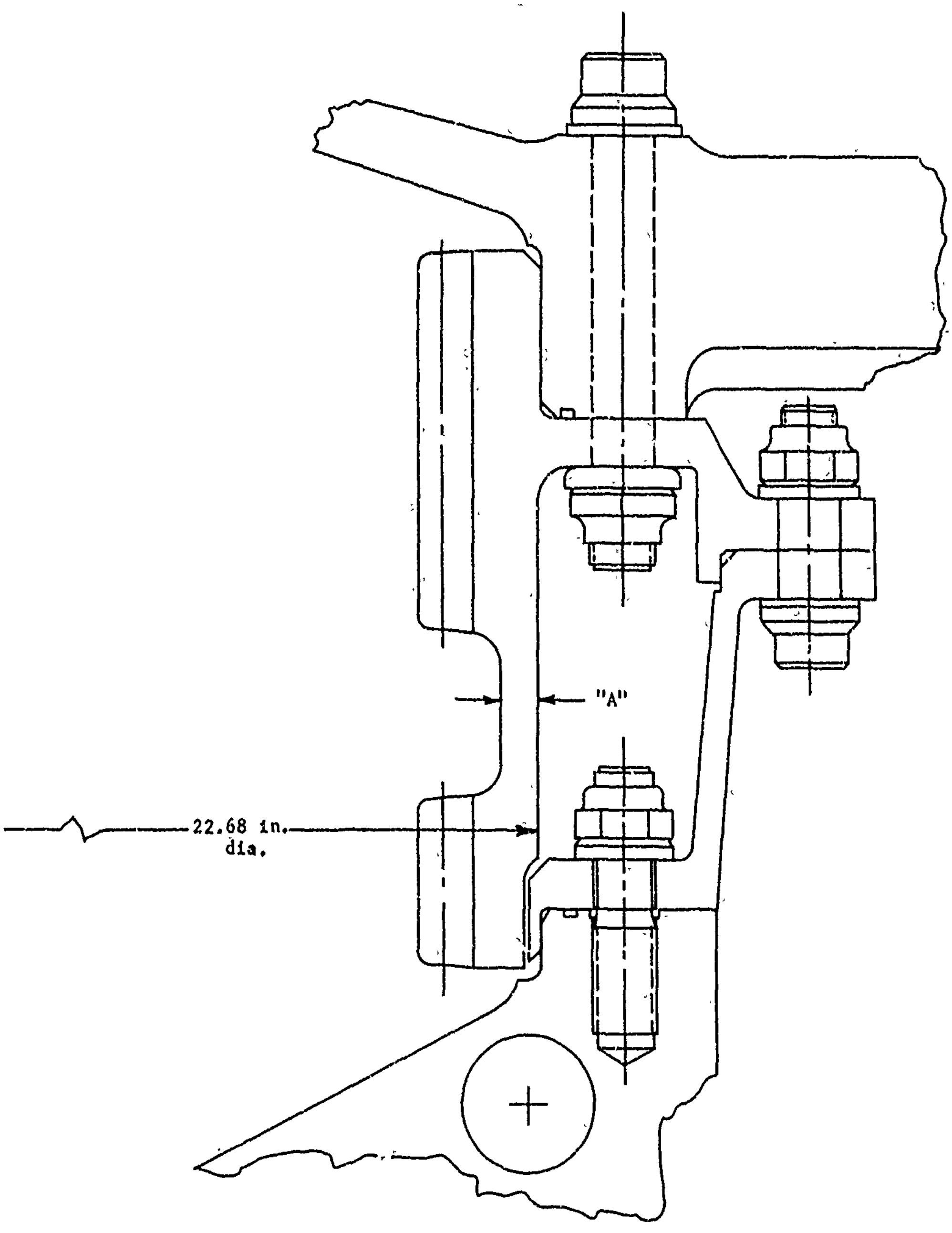



Figure 22. Peak Radial Vibration Amplitudes Perpendicular to the Ring-Gear Axis at Indicated Data Planes for Nominal Model.




| Modification | Dimension "A" |
|---|---|
| 1 | 0.28 in. |
| 2 | 0.45 in. |

Figure 23. Detailed Design of Modifications 1 and 2.

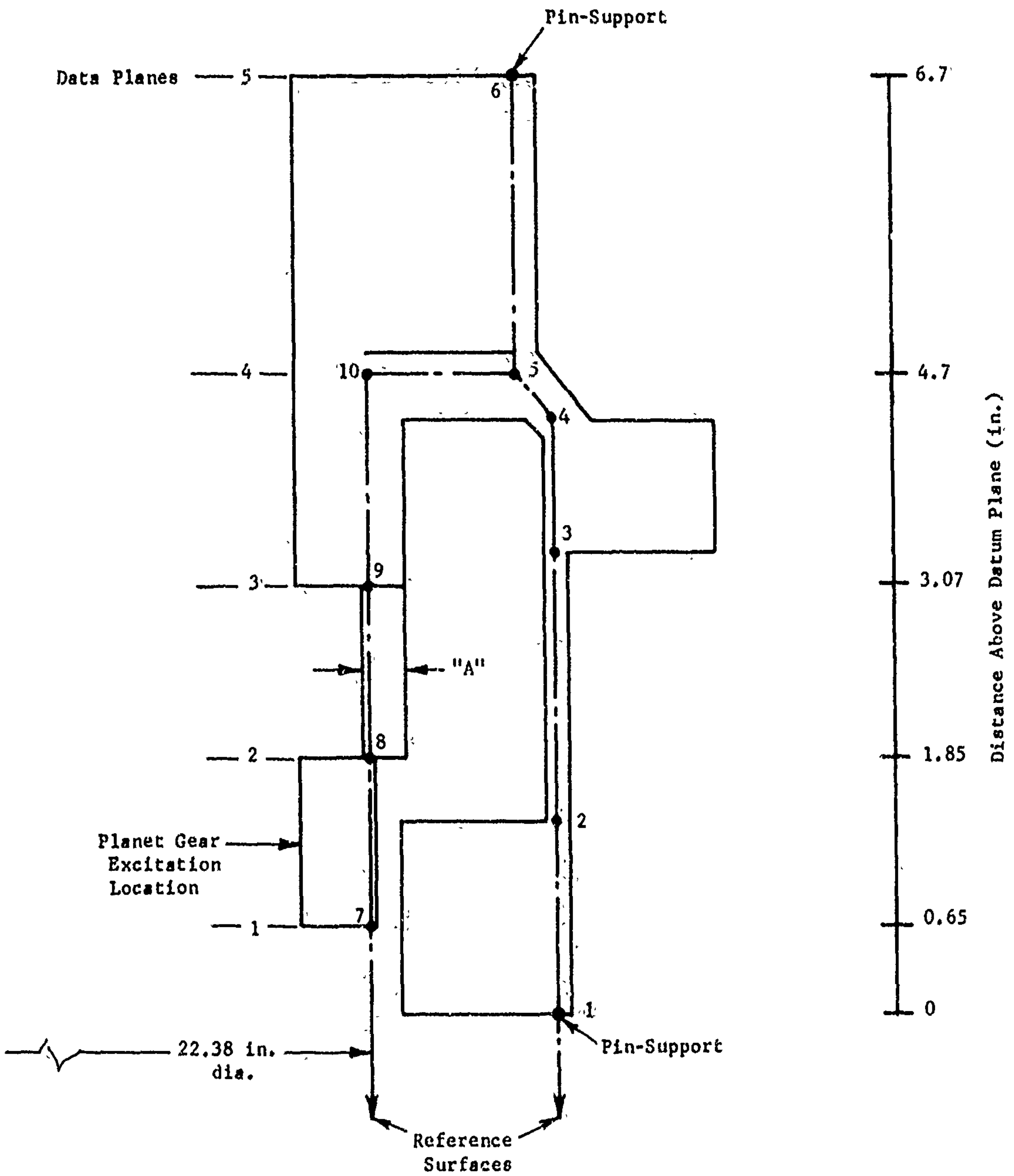



Figure 24. Analytical Model for Modifications 1 and 2.

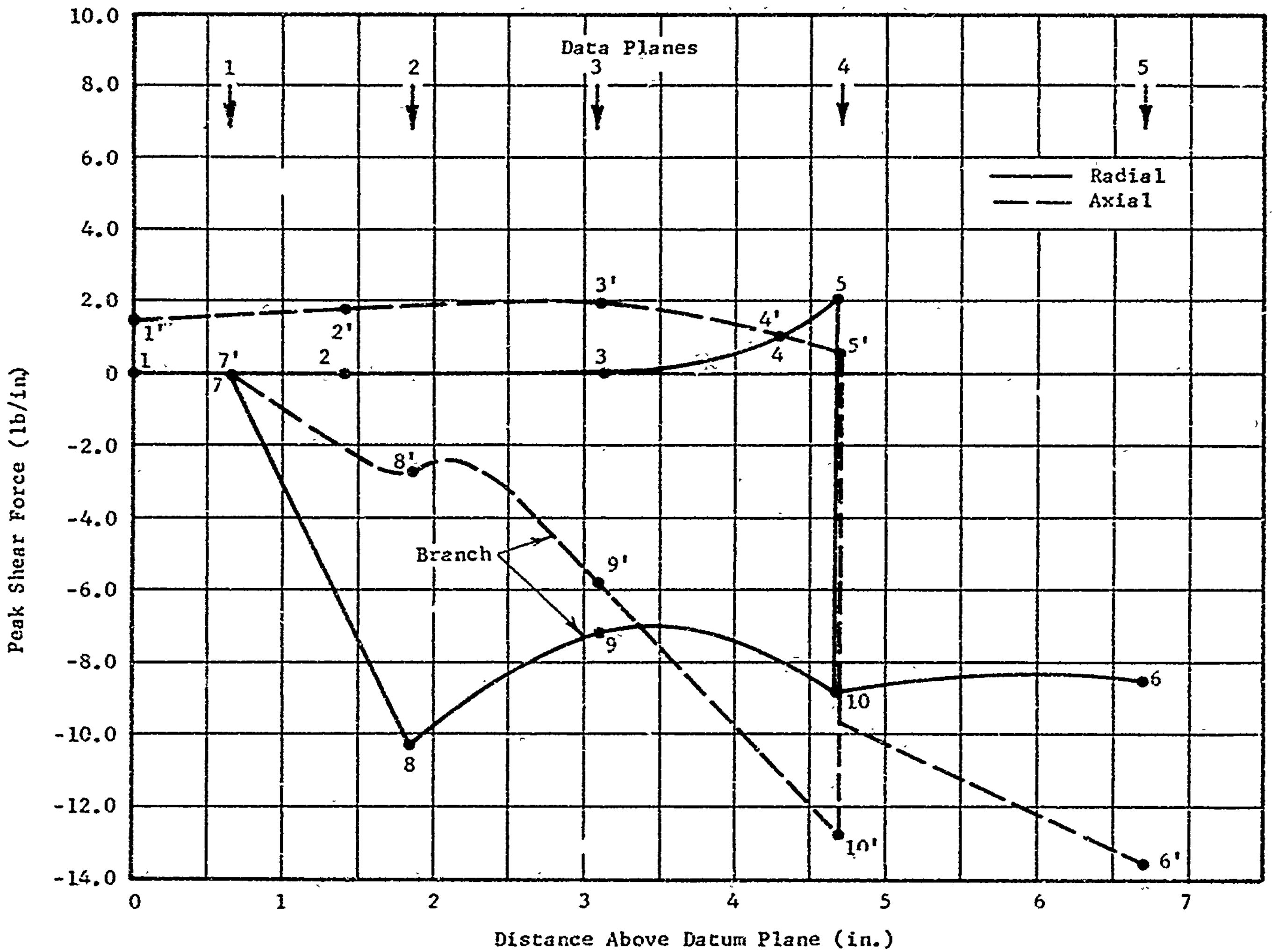



Figure 25. Peak Radial and Axial Dynamic Force Level For Modification No. 1.

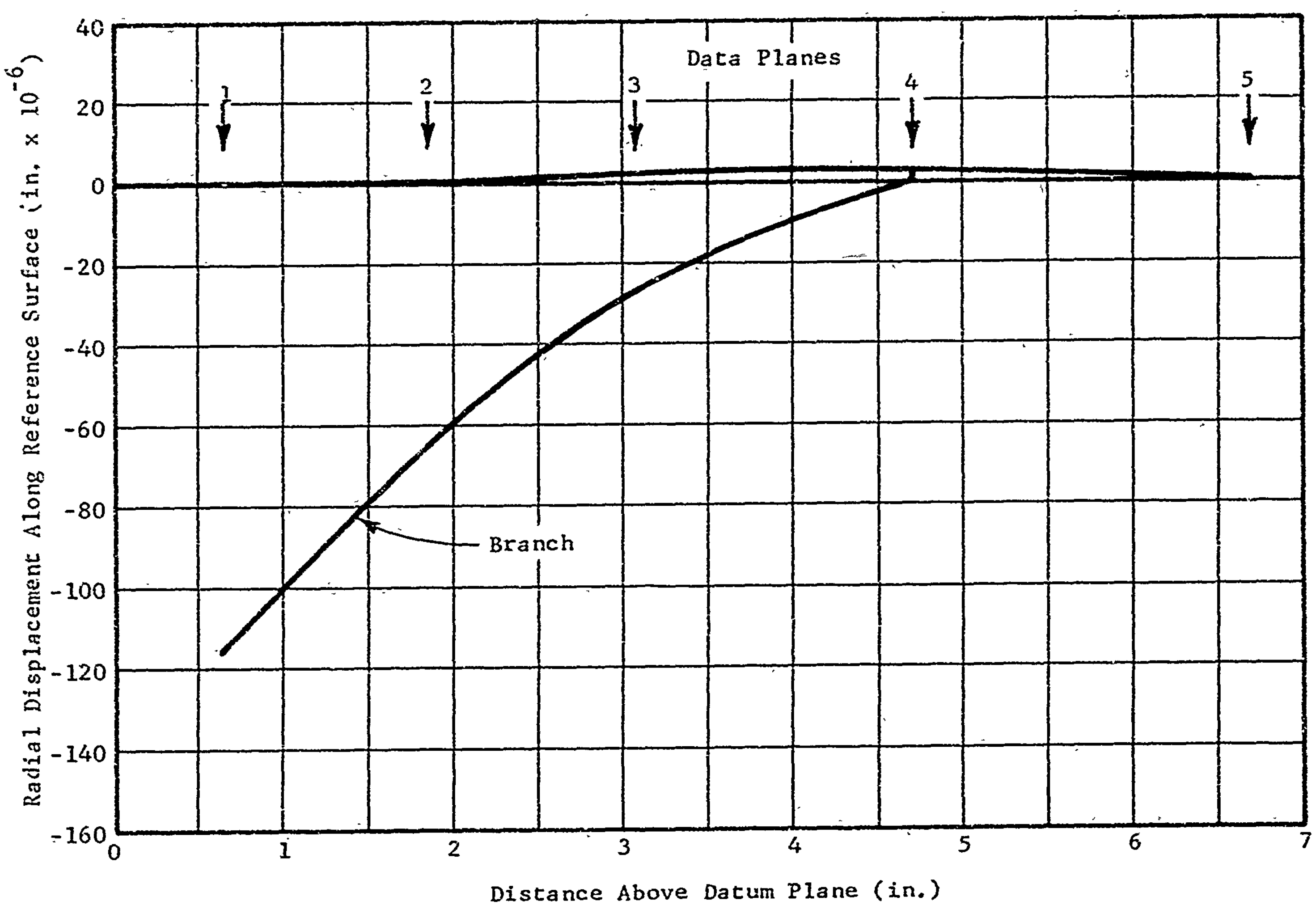



Figure 26. Peak Radial Vibration Amplitudes Along the Reference Surface at the Circumferential Location of the Dynamic Force for Modification No. 1.

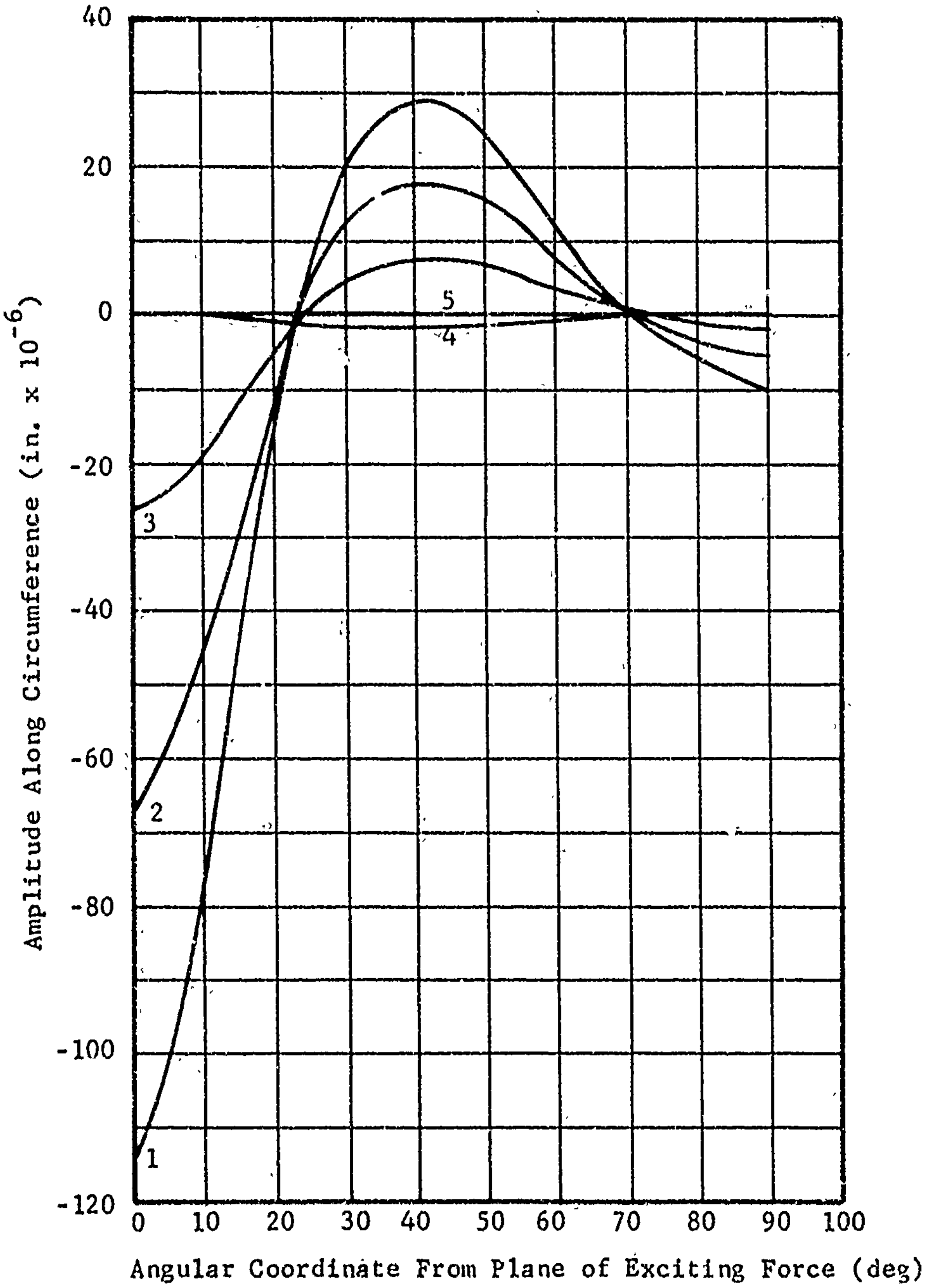



Figure 27. Peak Radial Vibration Amplitudes Perpendicular to the Ring-Gear Axis at Indicated Data Planes for Modification No. 1.

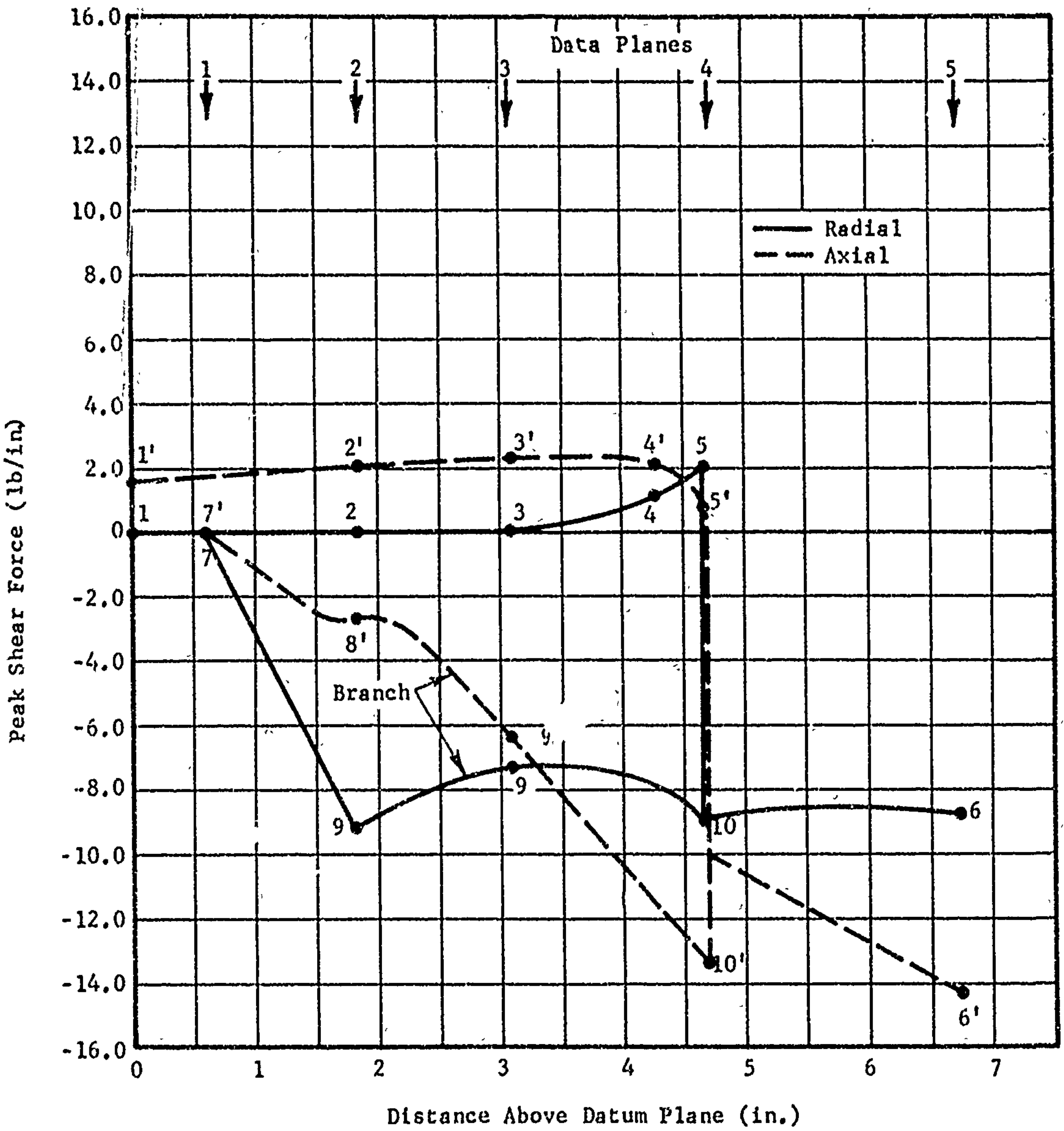



Figure 28. Peak Radial and Axial Dynamic Force Level for Modification No. 2.

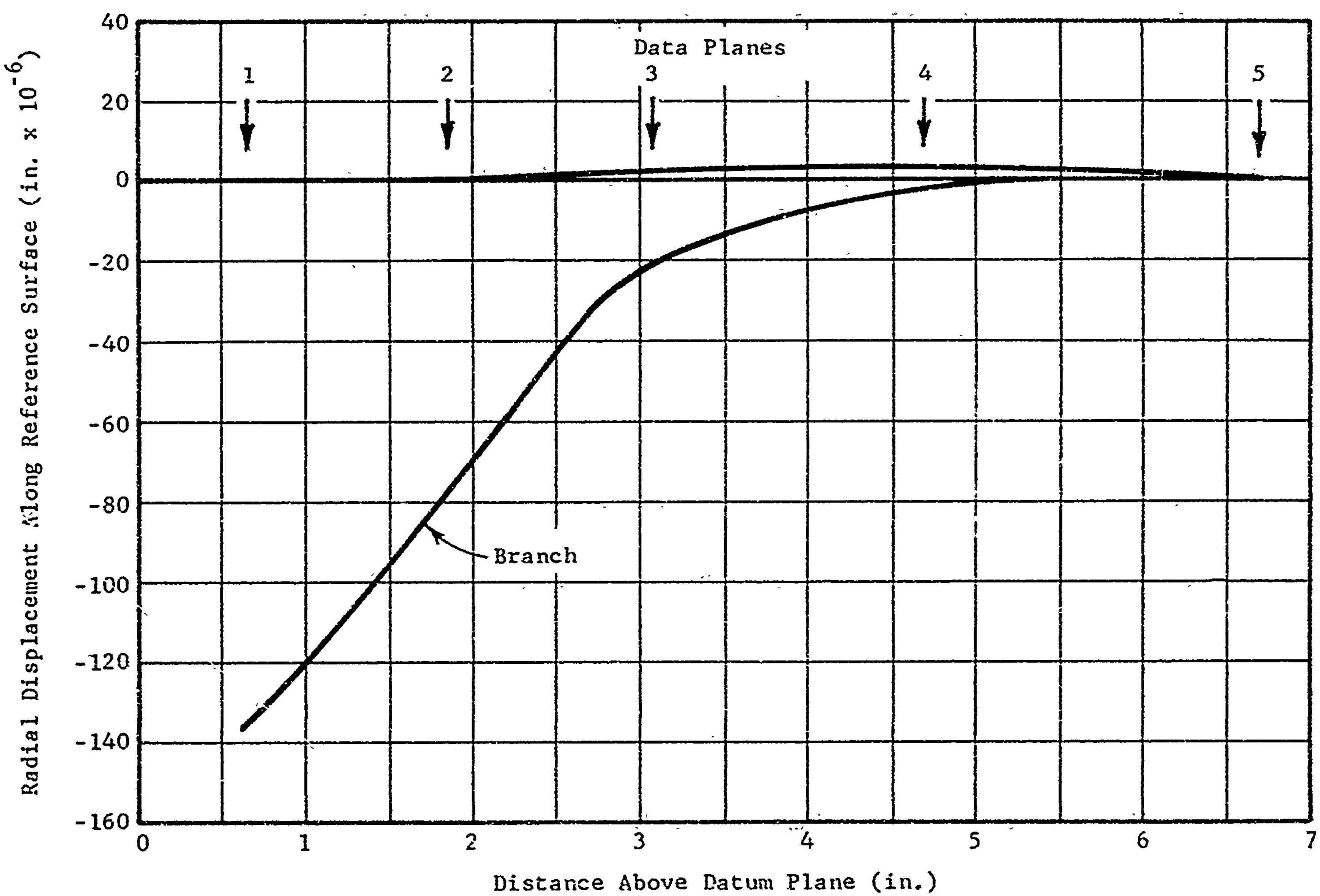



Figure 29. Peak Radial Vibration Amplitudes Along the Reference Surface at the Circumferential Location of the Dynamic Force for Modification No. 2.

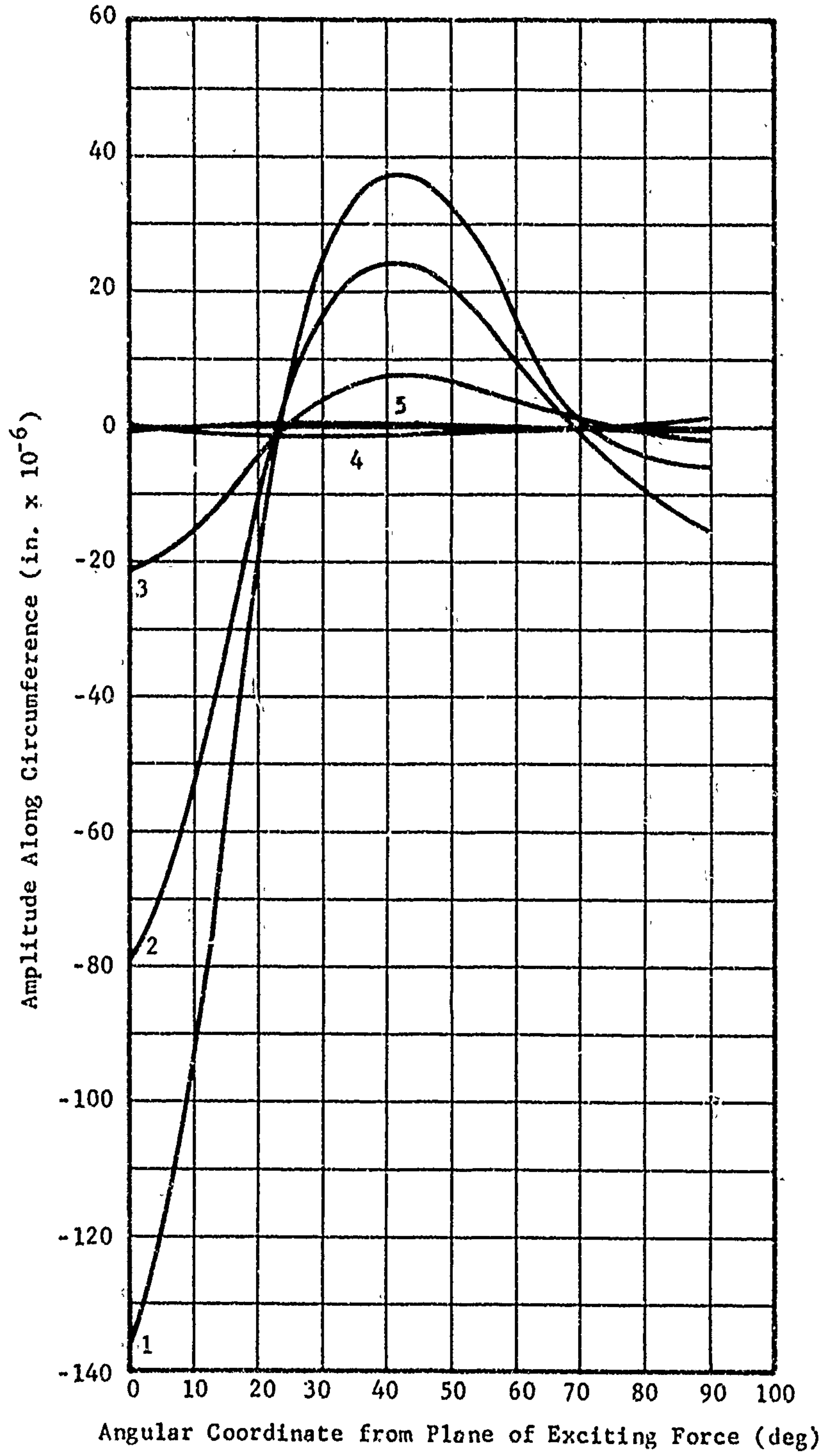



Figure 30. Peak Radial Vibration Amplitudes Perpendicular to the Ring-Gear Axis at Indicated Data Planes for Modification No. 2.

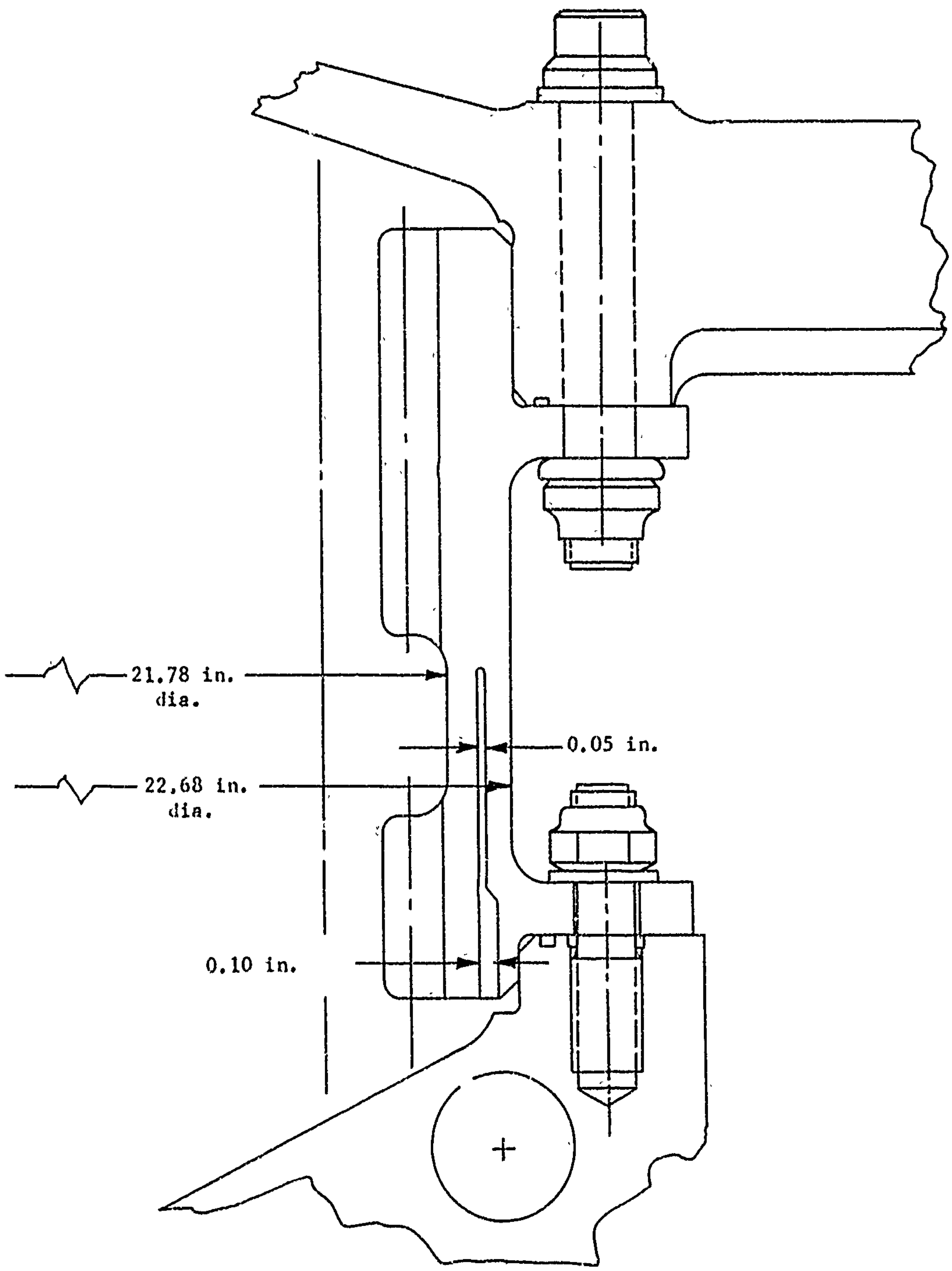



Figure 31. Detailed Design for Modification No. 3.

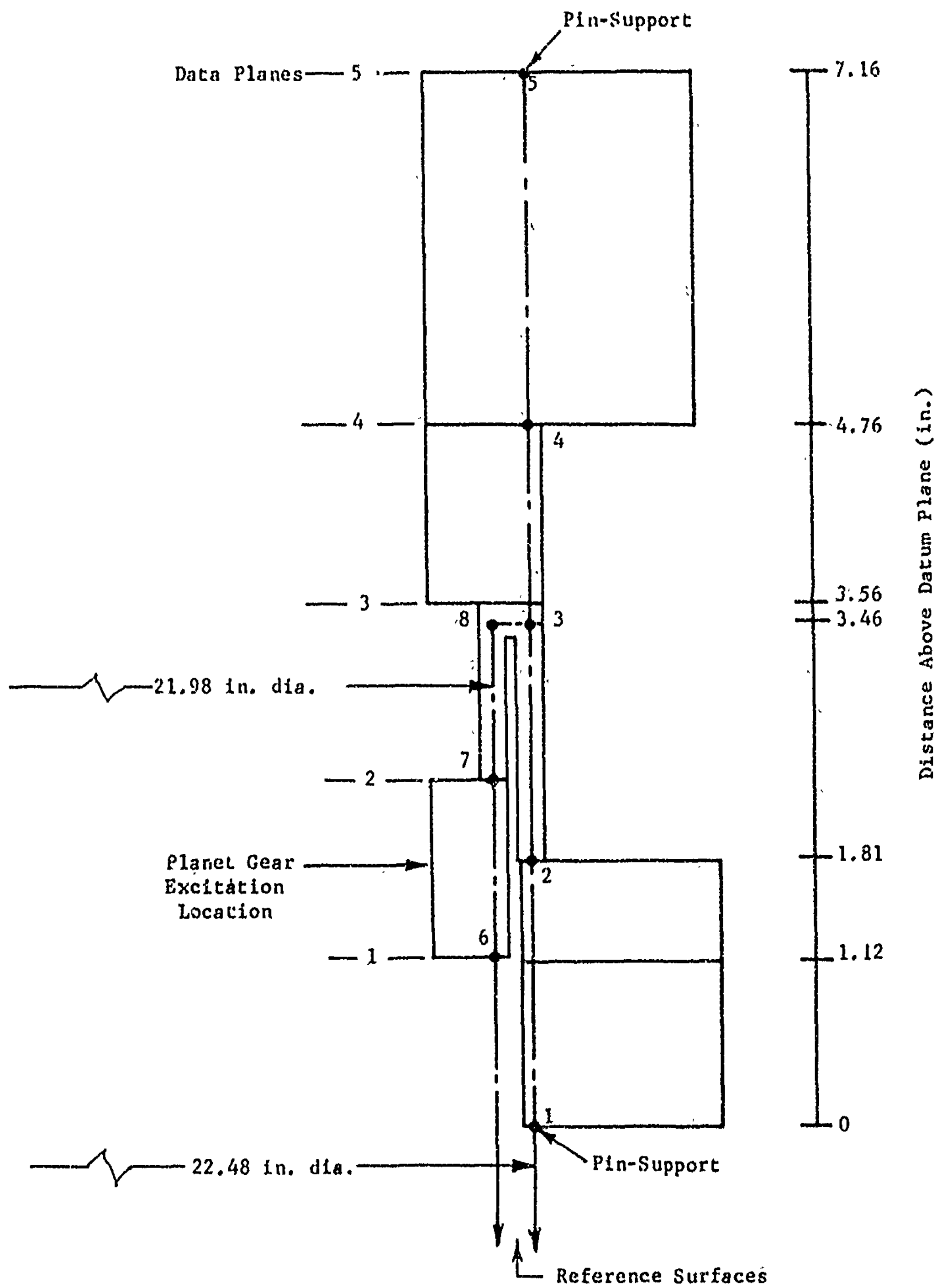



Figure 32. Analytical Model for Modification No. 3.

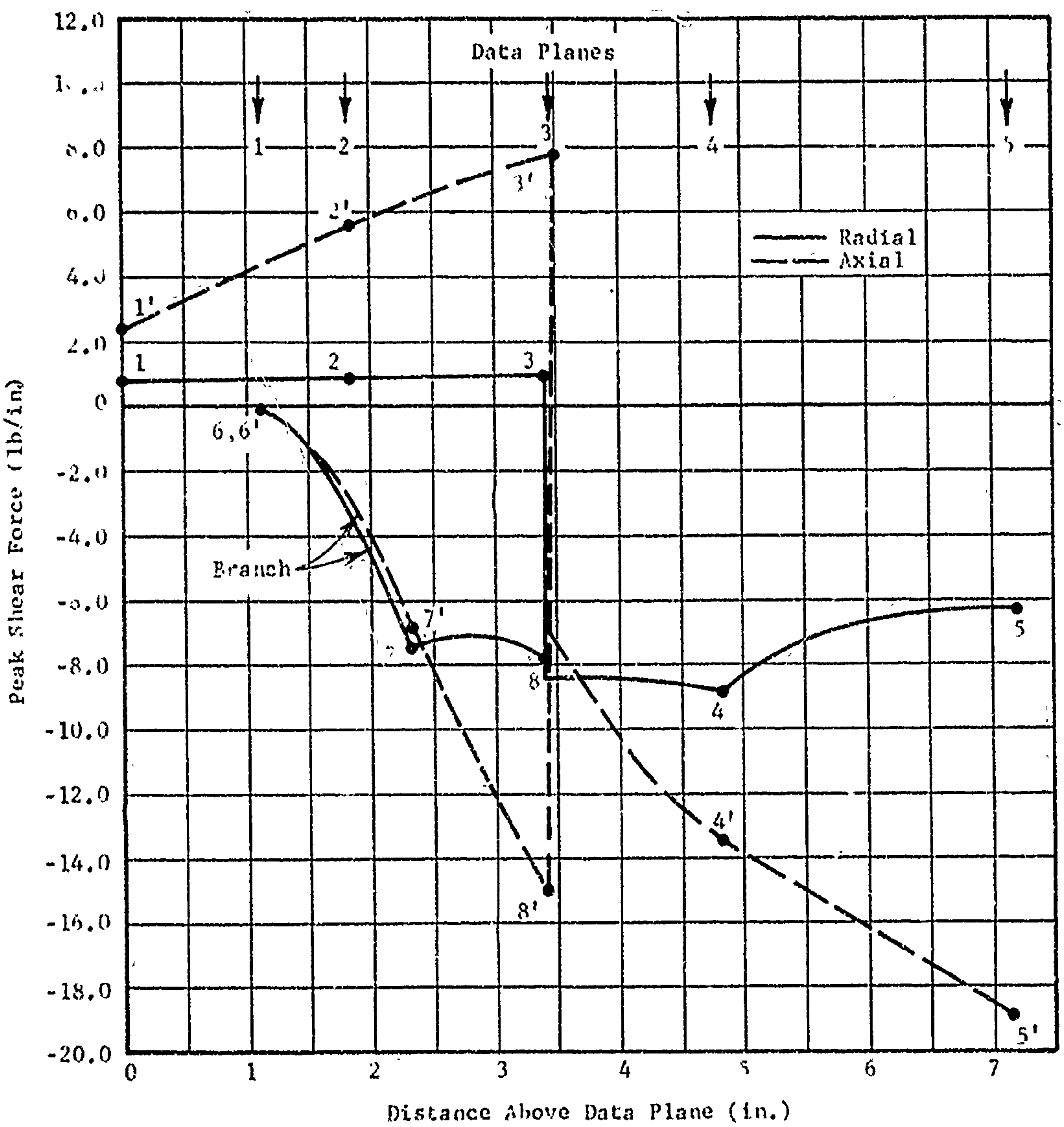



Figure 33. Peak Radial and Axial Dynamic Force Level for Modification No. 3.

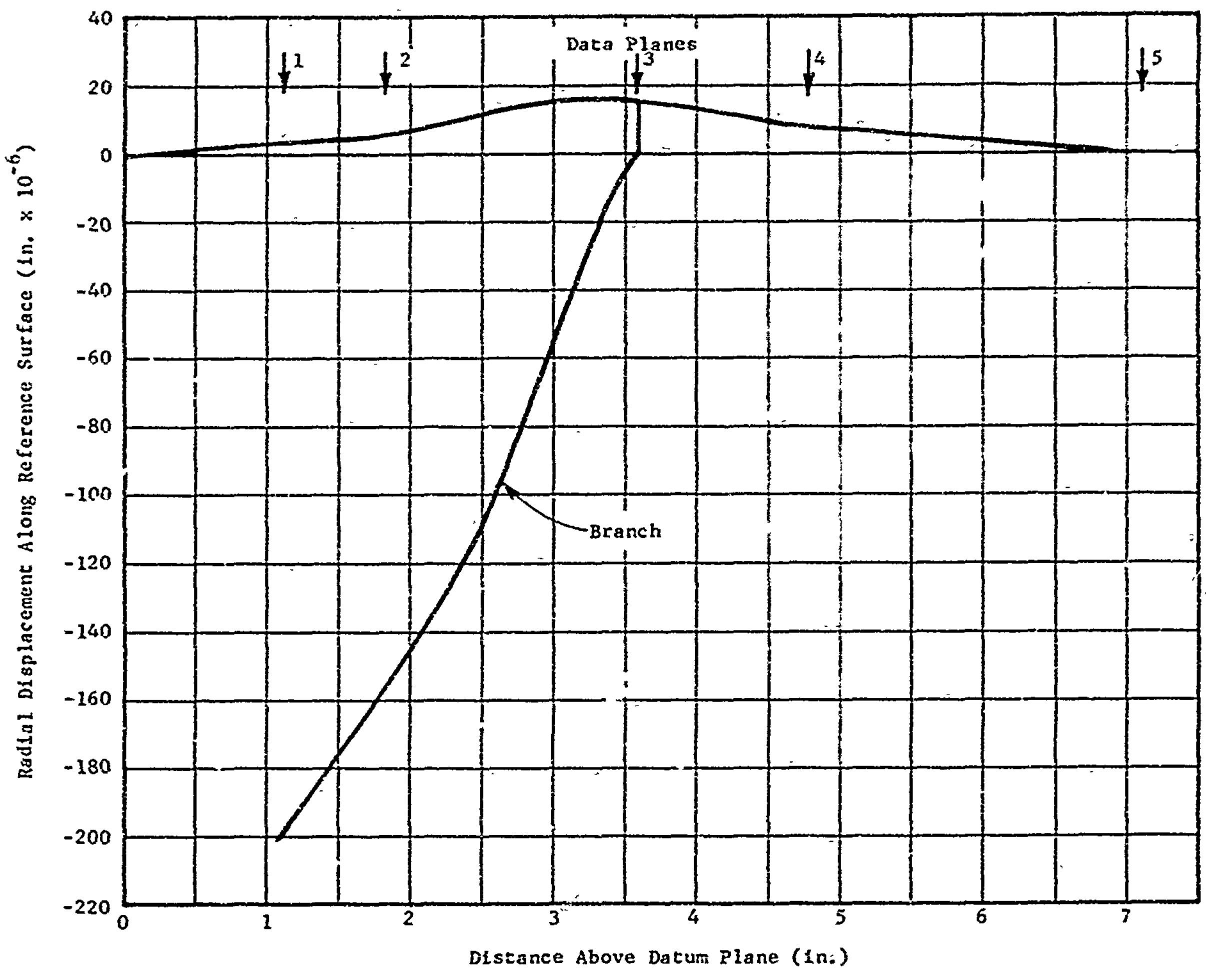



Figure 34. Peak Radial Vibration Amplitudes Along the Reference Surface at the Circumferential Location of the Dynamic Force for Modification No. 3.

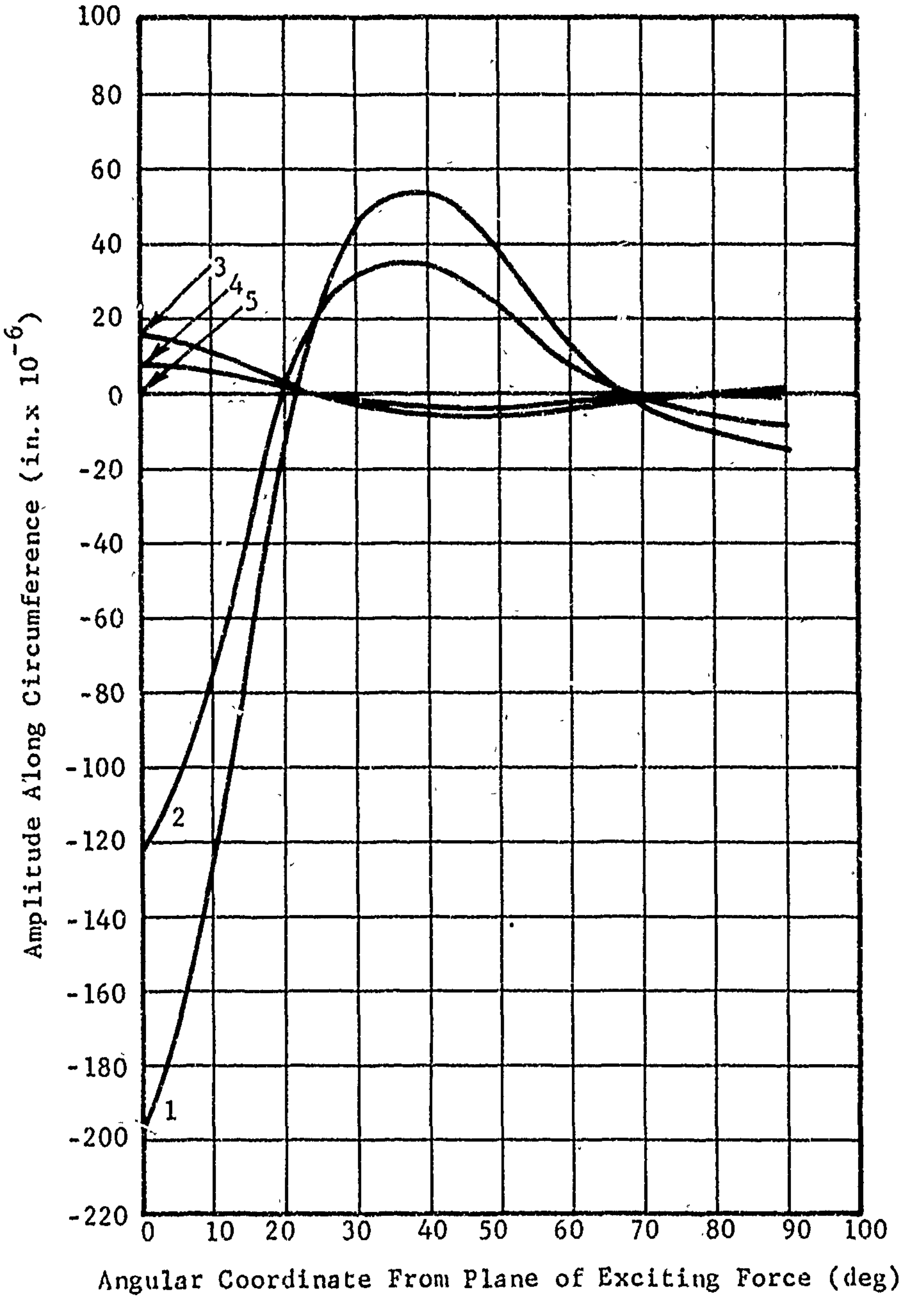



Figure 35. Peak Radial Vibration Amplitudes Perpendicular to the Ring-Gear Axis at Indicated Data Planes for Modification No. 3.

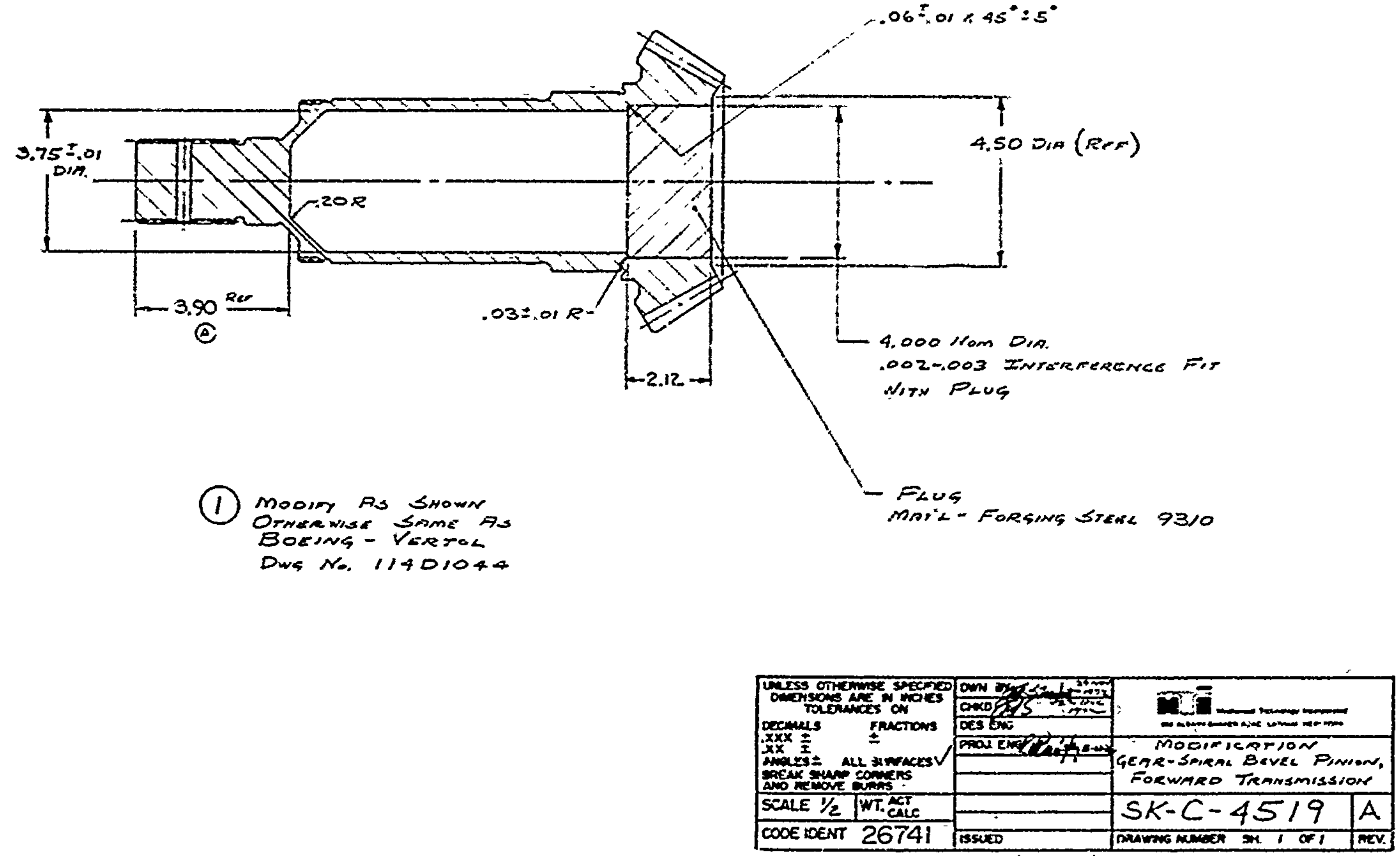



Figure 36. Modified Spiral Bevel Pinion Gear Shaft.

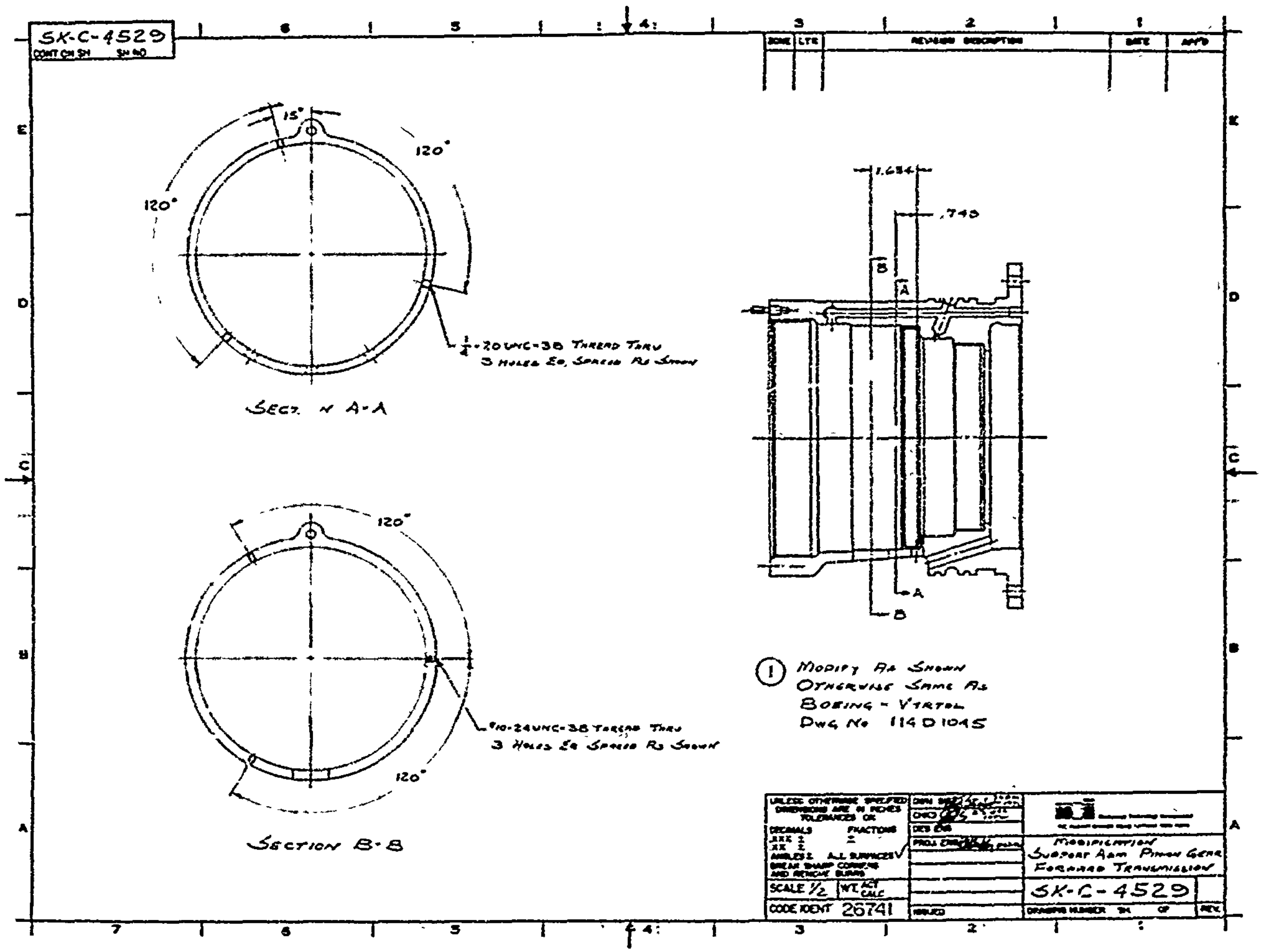
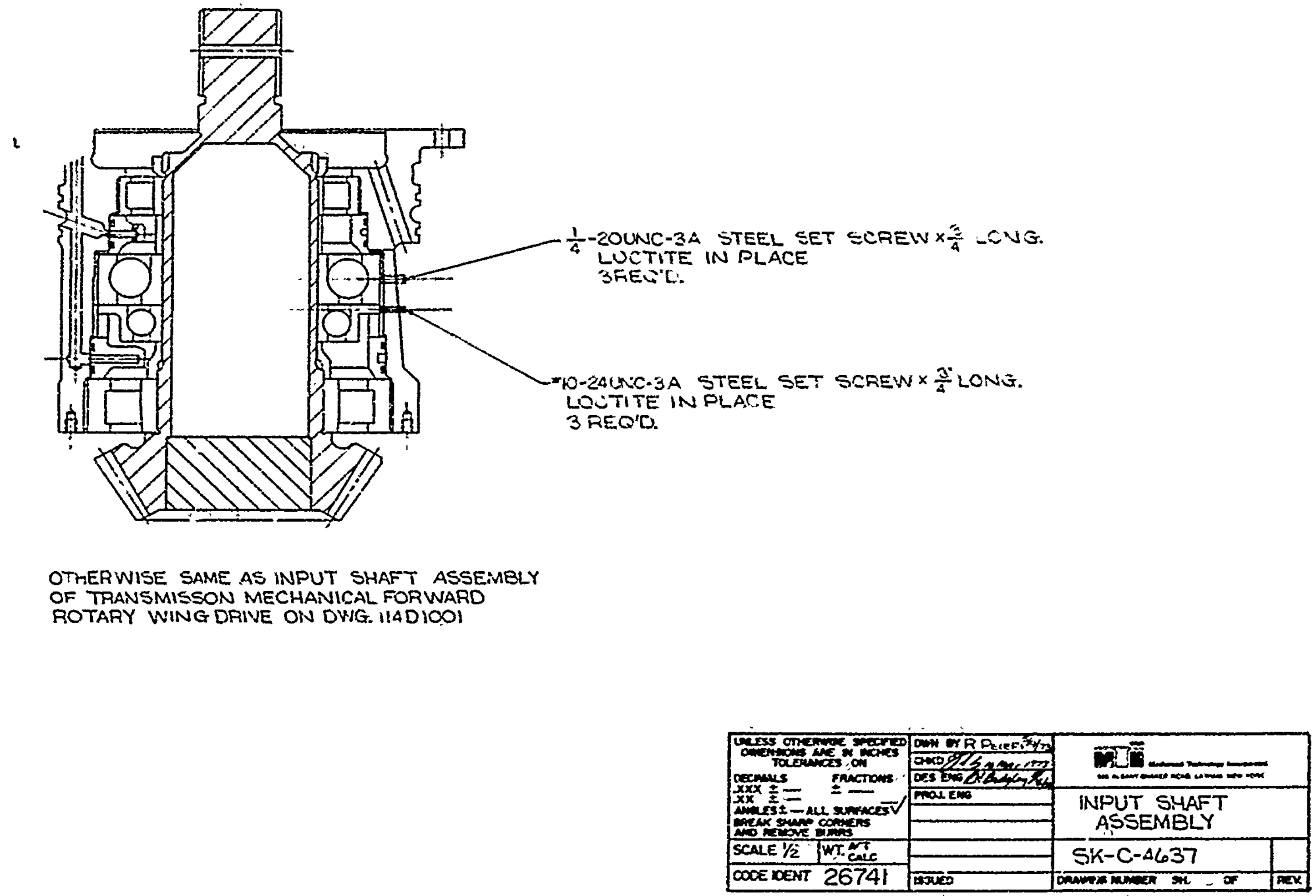



Figure 37. Modified Spiral Bevel Pinion Gear Shaft Mounting Support.




Figu 38. Subassembly Drawing of Modified Spiral Bevel Pinion Gear Shaft and Mounting Support.

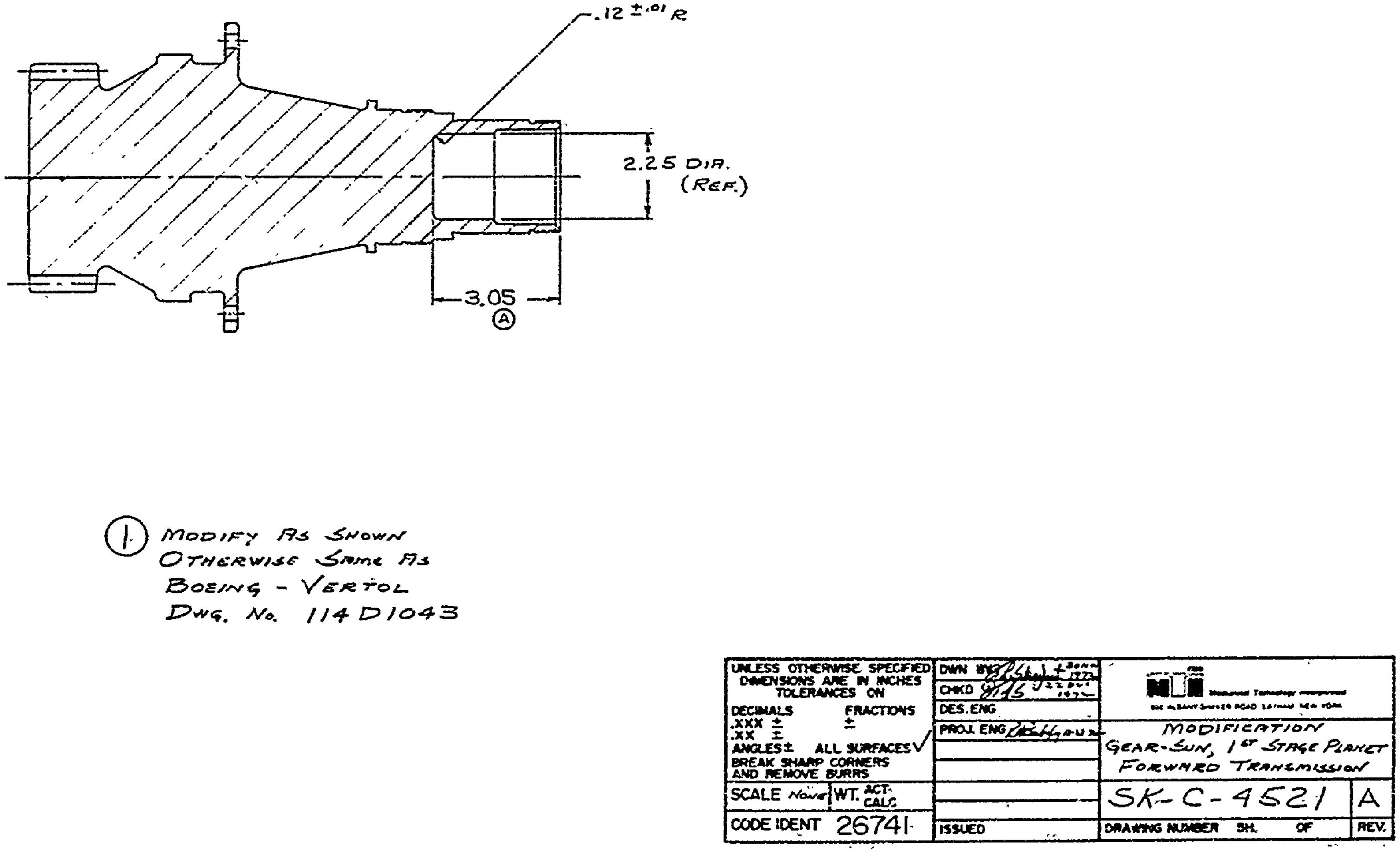



Figure 39. Modified First-Stage Planetary Sun Gear Shaft.

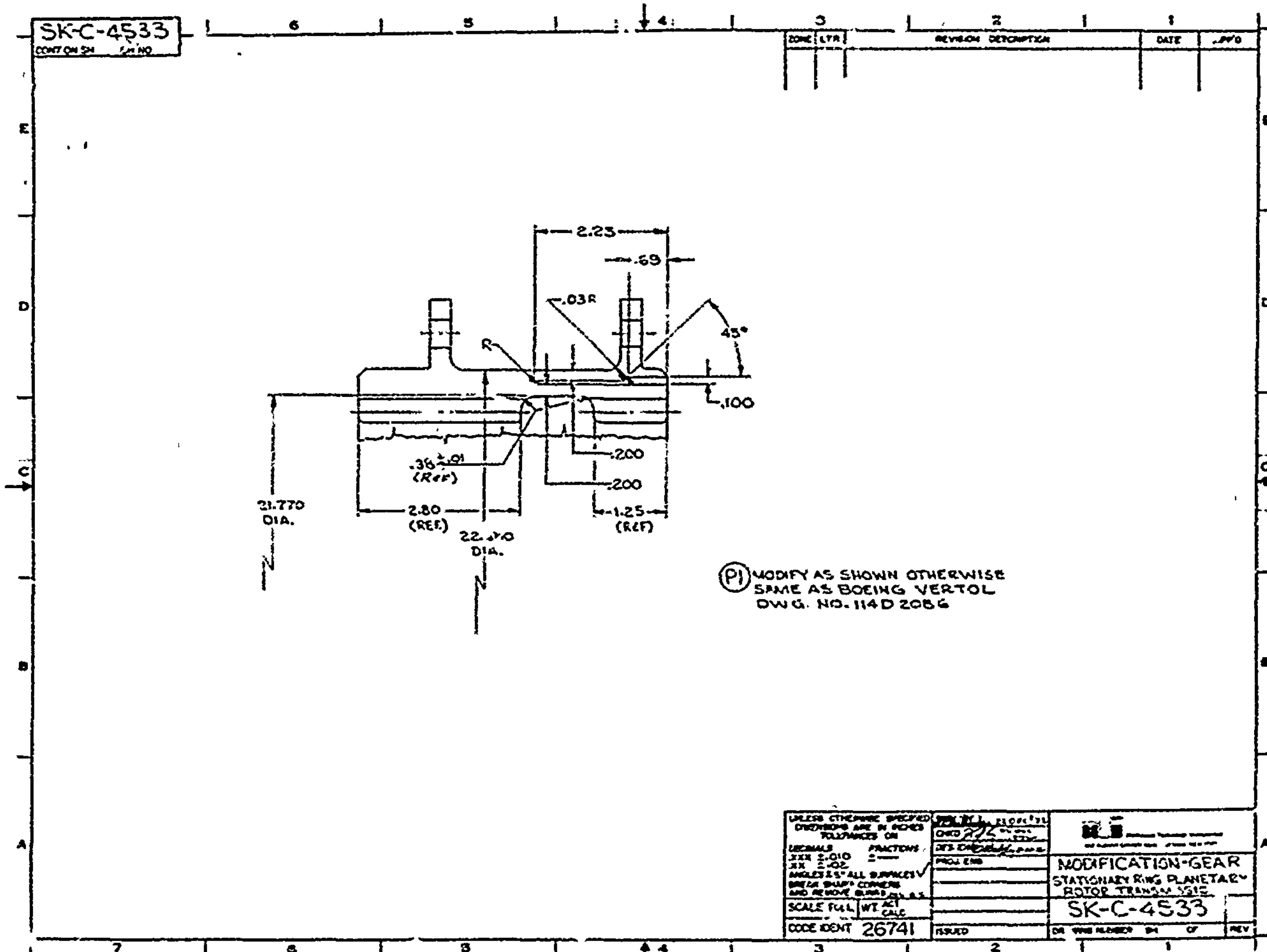



Figure 40. Modified Ring-Gear Cross-Section.

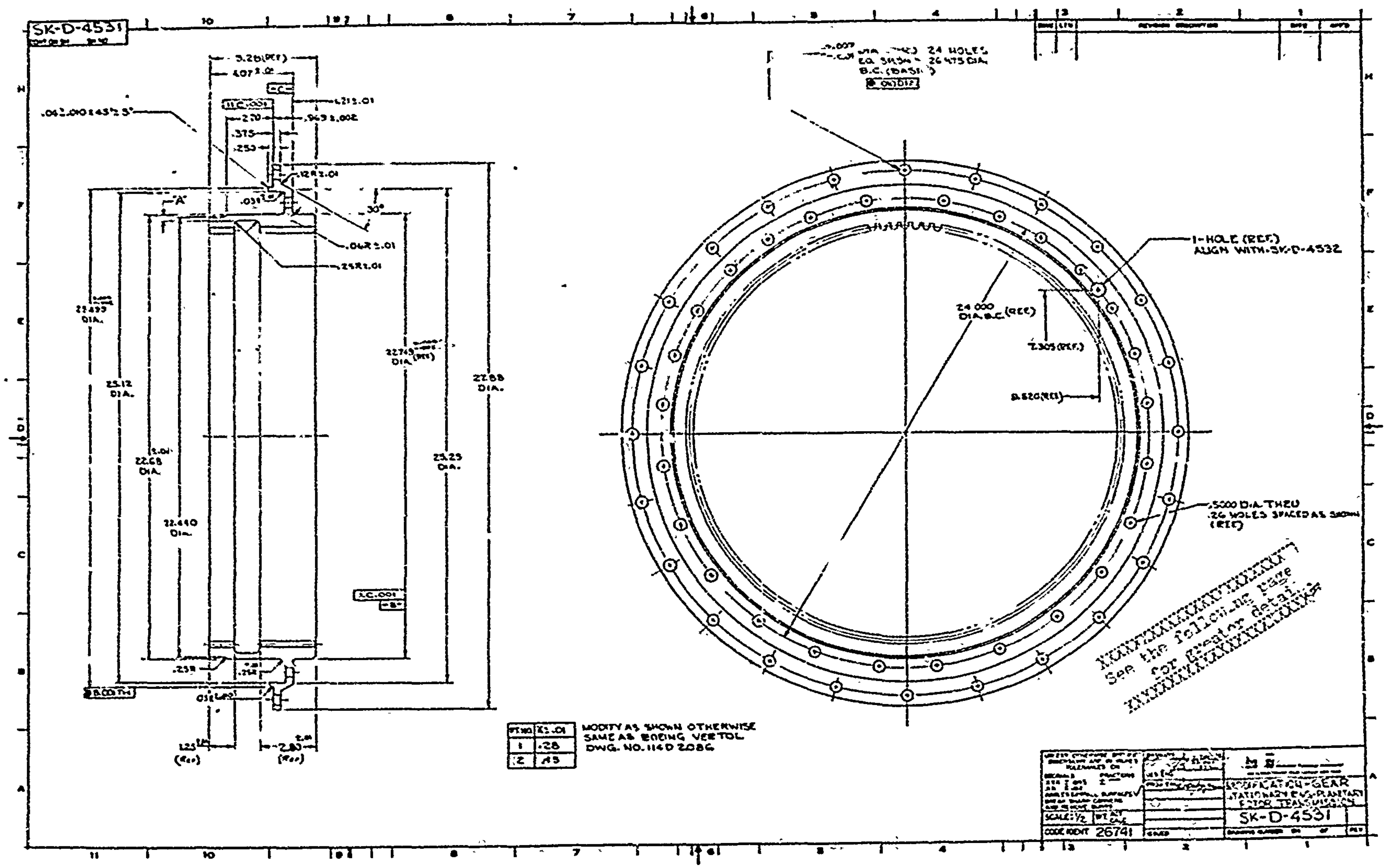



Figure 41. Modified Ring Gear

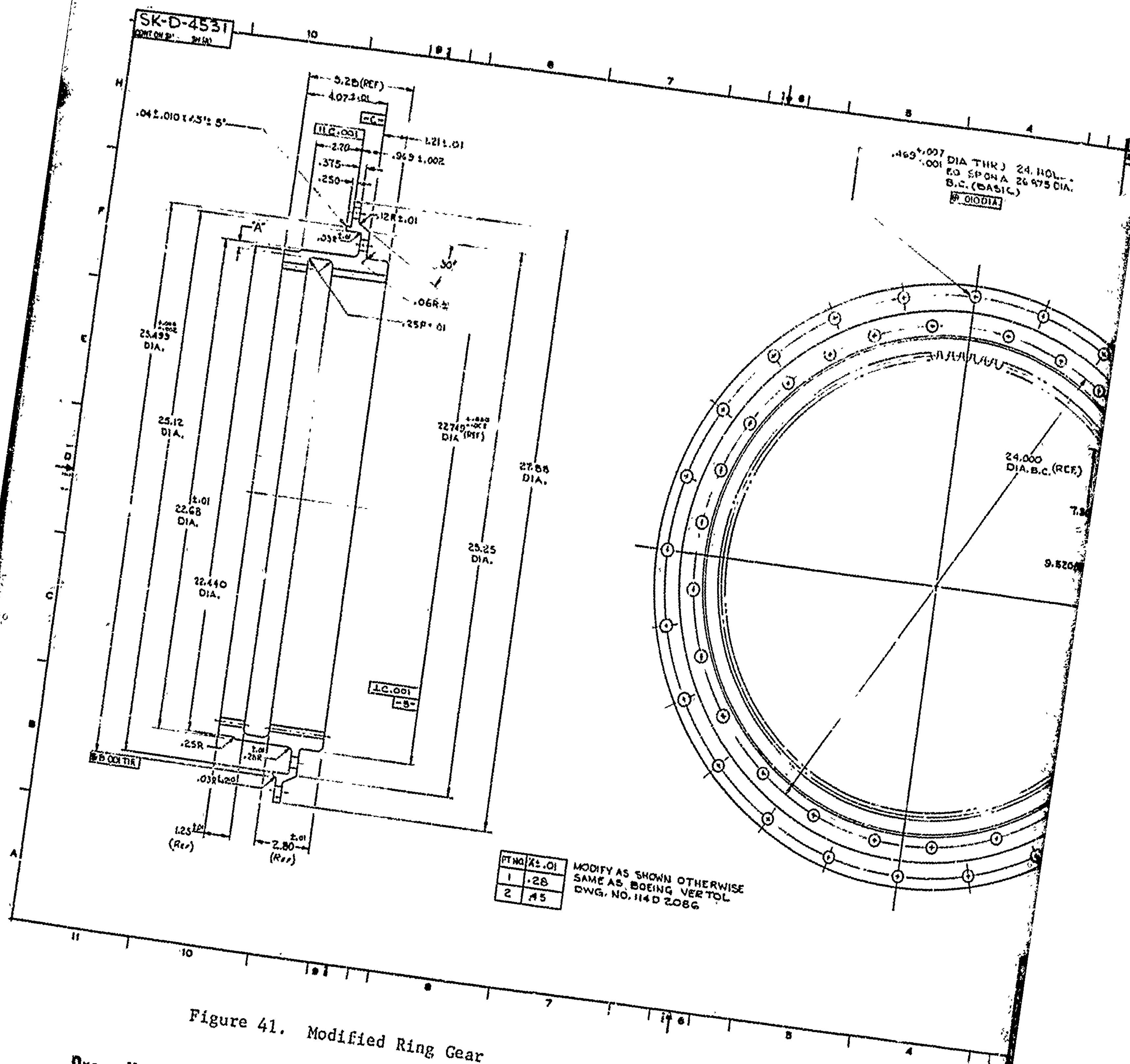


Figure 41. Modified Ring Gear

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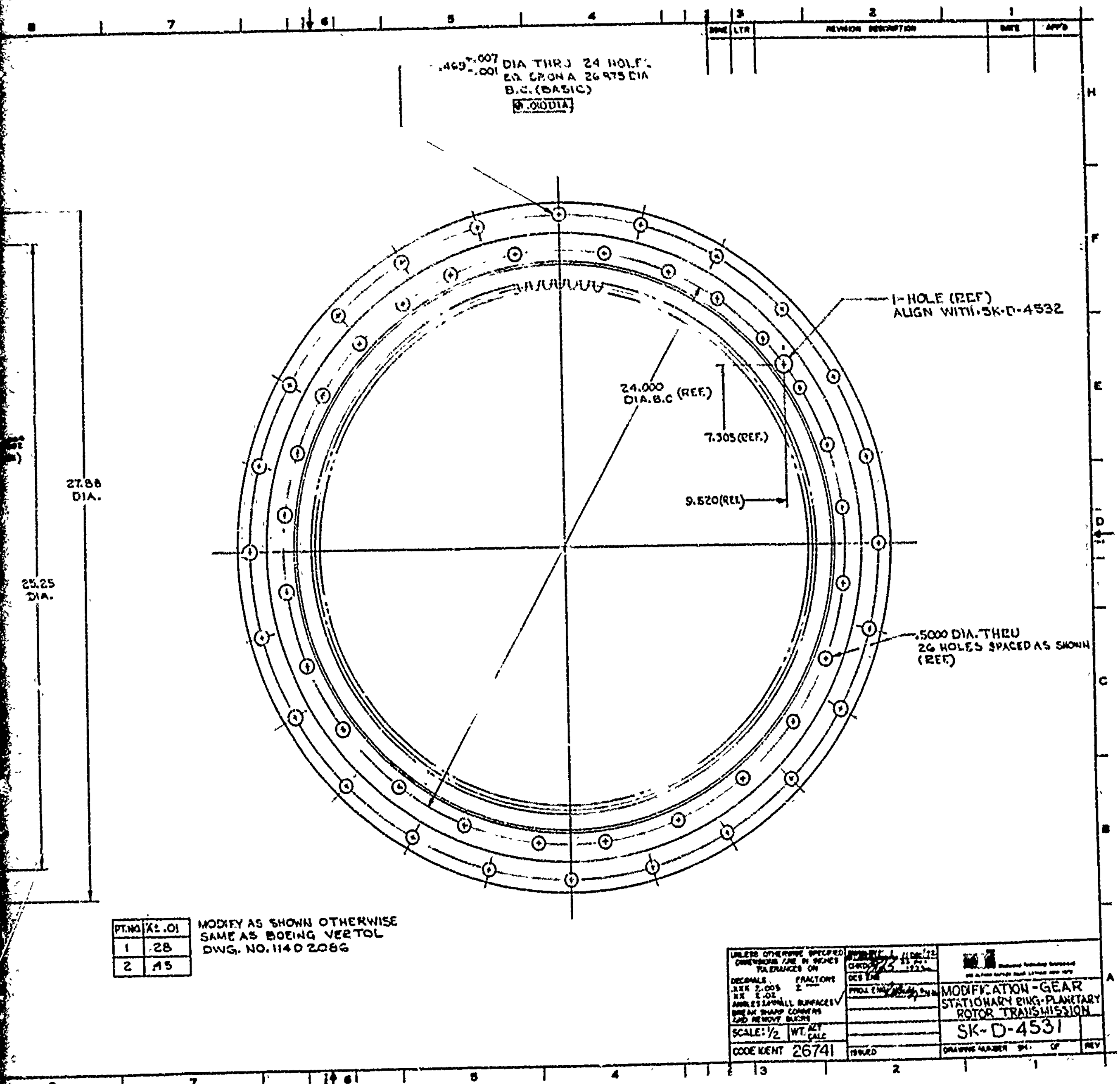
.469 +.007 -.001 DIA THRU 24 HOLES EQ SP ON A 26.975 DIA B.C. (BASIC)
.010 DIA
1-HOLE (REF) ALIGN WITH SK-D-4532
24.000 DIA. B.C (REF.)
7.305 (REF.)
9.520 (REF.)
27.88 DIA.
25.25 DIA.
.5000 DIA. THRU 26 HOLES SPACED AS SHOWN (REF)
PT.NO | X ± .01
1 | .28
2 | .45
MODIFY AS SHOWN OTHERWISE SAME AS BOEING VERTOL DWG. NO. 114D2086
MODIFICATION - GEAR STATIONARY RING - PLANETARY ROTOR TRANSMISSION
SK-D-4531
SCALE: 1/2
CODE IDENT 26741
REVISION DESCRIPTION
DATE
APP'D

Ring Gear

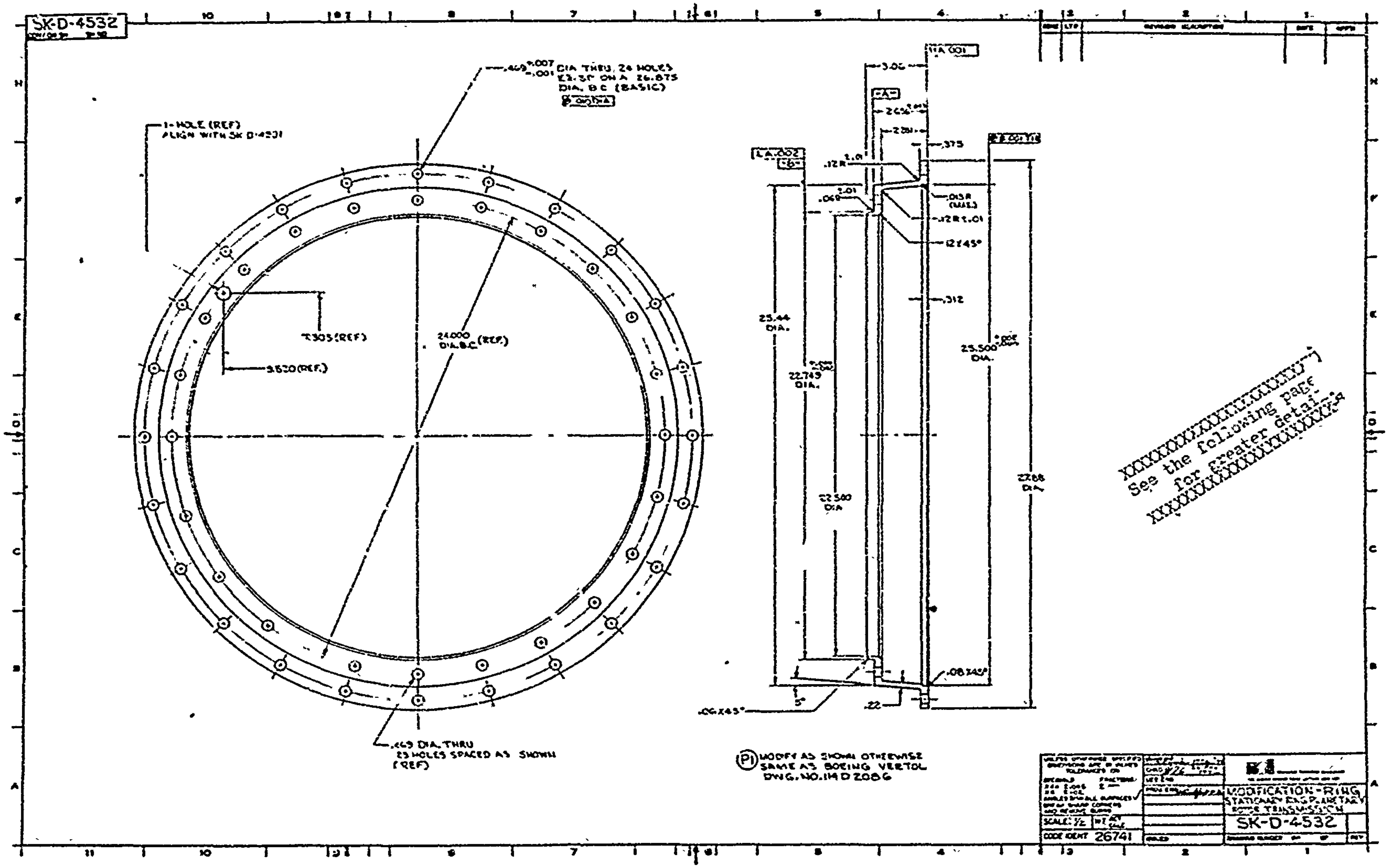


Figure 42. Modified Ring-Gear Support Ring.

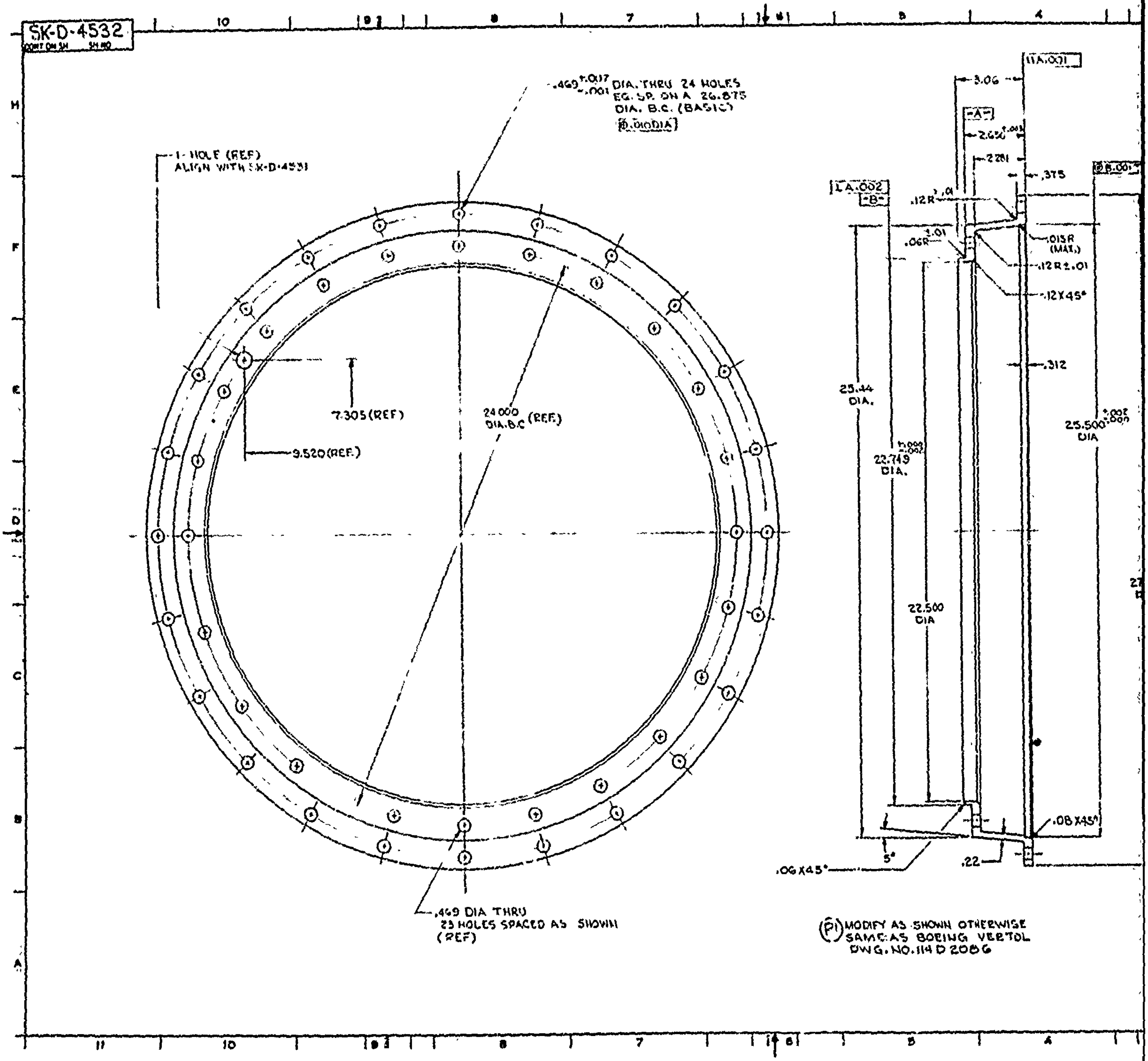


Figure 42. Modified Ring-Gear Support Ring.

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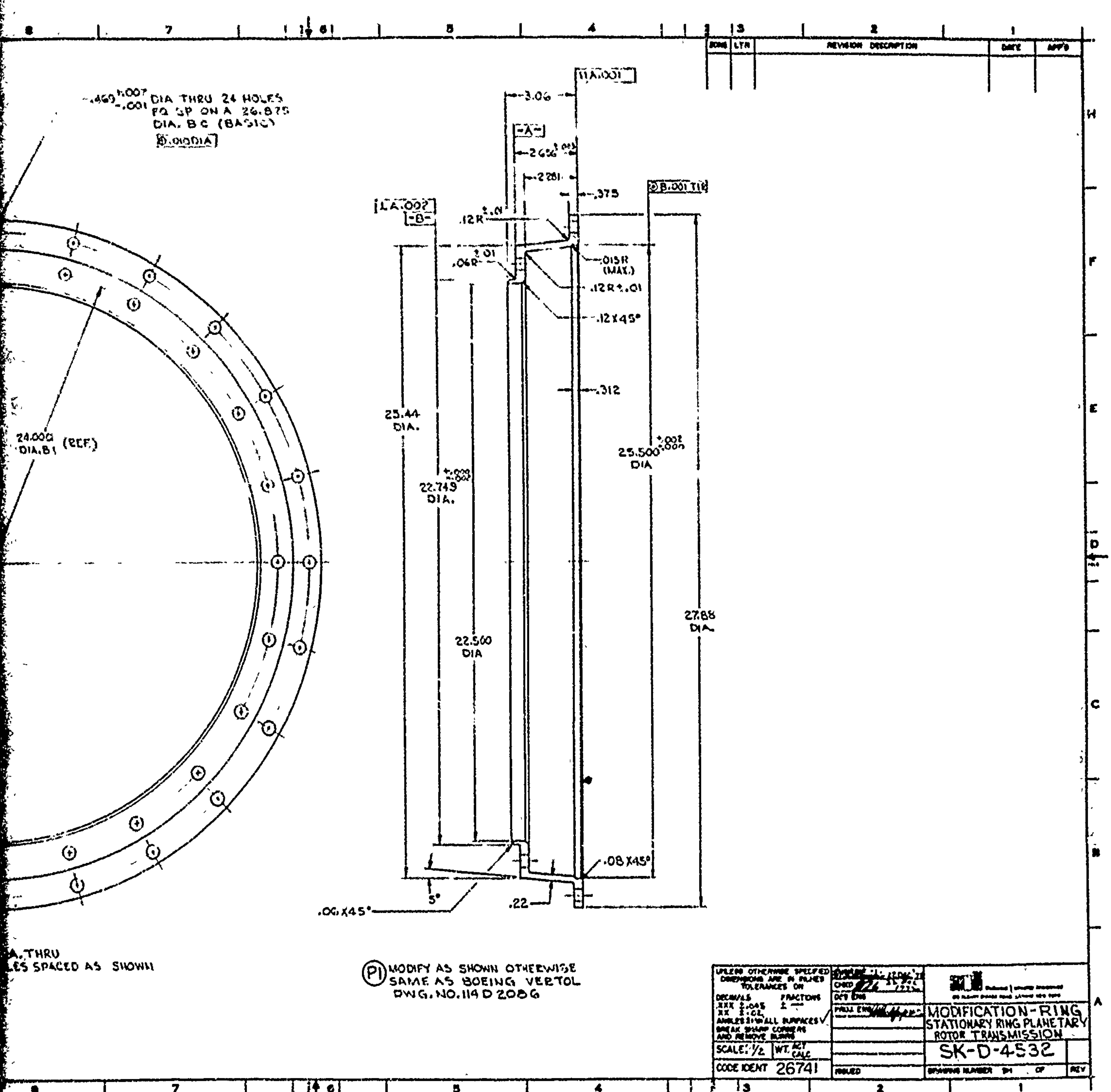


ar Support Ring.